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Land Treatment of Municipal Wastewater Effluents

Design Factors-II

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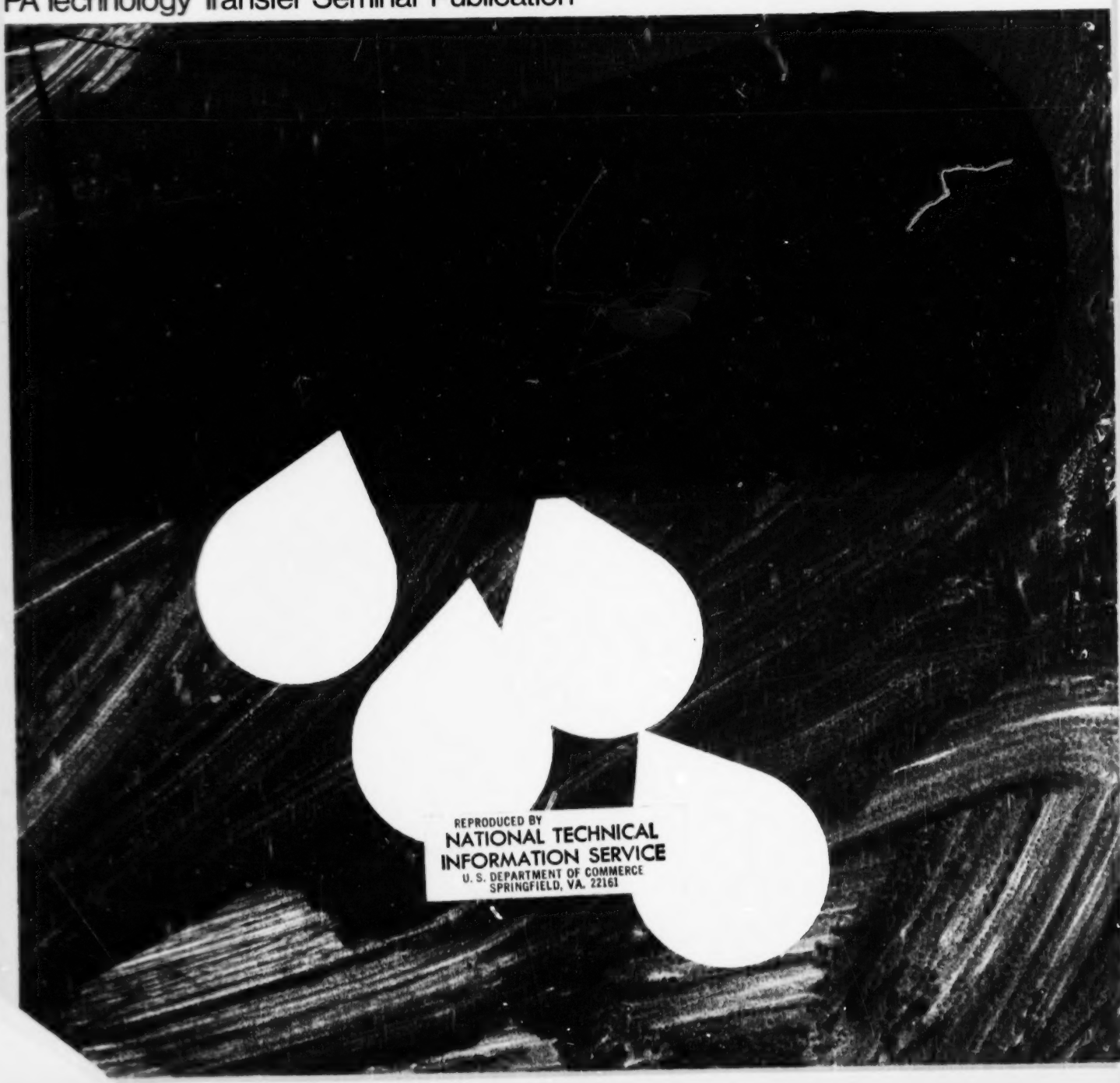

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DESIGN FACTORS – II

ENVIRONMENTAL PROTECTION AGENCY • Technology Transfer

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CONTENTS

	Page
Introduction	1
	3
Chapter I. Land Application Processes	3
Overland Flow	6
Irrigation	6
High-Rate Irrigation	7
Infiltration-Percolation	9
	9
Chapter II. Factors Affecting Site Selection	9
Soil	12
Geology and Groundwater	12
Land Use	12
Sensitive Environmental Areas	17
Water Rights	18
Land Application Process	18
Topography	19
Political Boundaries and Land Ownership	21
	21
Chapter III. Identifying and Selecting Sites	23
Criteria for Potential Area Identification	23
Potential Sites	29
Site Evaluation and Selection	29
	31
Chapter IV. Effluent Loading Characteristics	40
Infiltration	46
Permeabilities of Soil and Geologic Materials	46
Nitrogen Removal	48
Nitrogen Balance	49
Phosphorus	49
Suspended Solids	52
BOD and COD Oxidation	53
Inorganic Chemicals	55
Salts	55
Climate	55
	57
Chapter V. Effluent Loading Design	
Climate and Hydrology	
Process Loading	
Rest Period	

Page

Chapter VI. Components of Land Application Systems 59
System Components 59
Operation Components 63

Chapter VII. Alternative Evaluation 67

References 69

INTRODUCTION

This is the second of two papers prepared for the United States Environmental Protection Agency Technology Transfer Program on Land Treatment of Municipal Wastewater Effluents. Land treatment or land application is the treatment of wastewater by using plant cover, soil surface, soil profile, and geologic materials to remove certain wastewater pollutants. Figure 1 is a conceptual drawing of the relationship of land application to the entire water cycle, from the water supply to the treatment and disposal of the used water. Once applied to the land, a portion of the water is lost to evaporation and transpiration, and the remainder returns to the groundwater or surface water. Many pollutants are removed by the soil and plants as the wastewater moves through the vegetation and soil profile.

The main concern about using land application for wastewater treatment is the possible harmful effects of the pollutants on the vegetation, soil, and surface and groundwaters. To

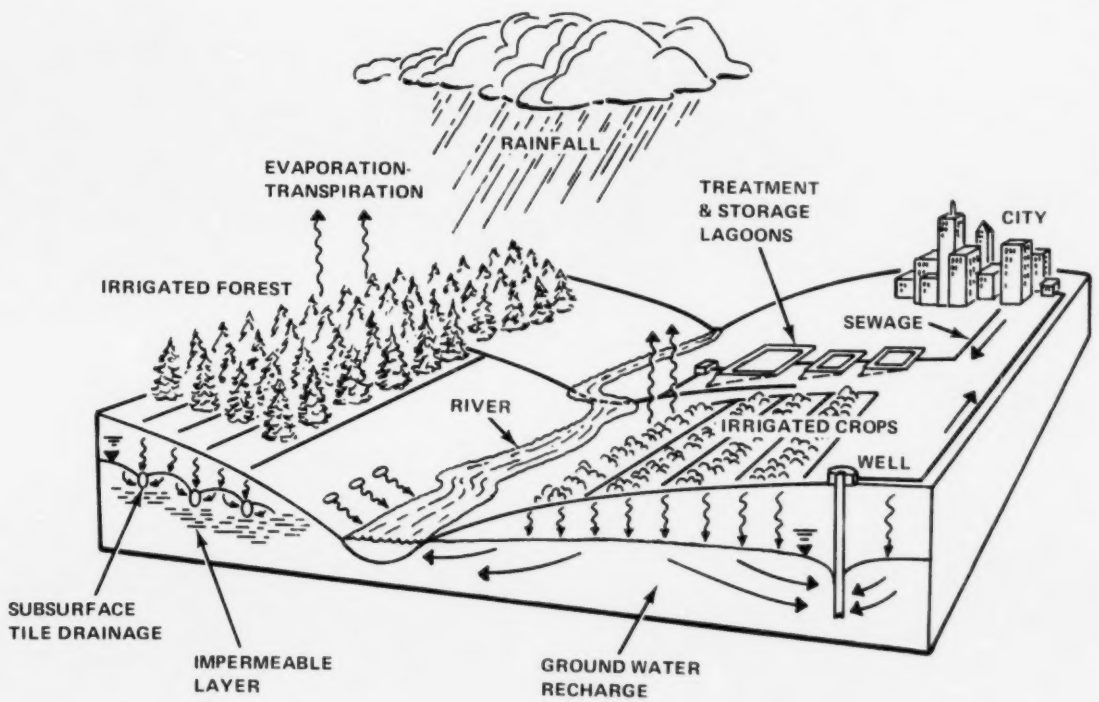

Figure 1. Conceptual land application of wastewater effluents.[1]

avoid adverse environmental impacts, many factors such as soil and crop characteristics and wastewater makeup must be considered in designing a land application system. Consequently, a land application method of treating municipal wastewater is specifically designed for a selected site. The design for one site cannot normally be used at another location.

A main theme of many papers presented at the Second National Groundwater Quality Symposium held in Denver in September 1974 was that wastes applied to land pollute the groundwater. The only way to completely eliminate that pollution is to isolate the waste from the environment. Isolation can be accomplished by surrounding the waste with a water impermeable material. This is, of course, impossible to do with the wastewater volumes from cities and furthermore would be a waste of the water as a valuable resource. The objective of land application of wastewater should be to treat the water with due consideration to impacts on the environment. This part discusses many design factors which are part of or which impact the manmade and natural environments. The impacts can be minimized by giving proper consideration to these factors.

A multidisciplinary approach to defining and evaluating land application alternatives is usually required. Some of the technical areas involved in investigating land application include hydrogeology, soil science, agronomy, and engineering. Other disciplines that may also be relevant depending on the type and place of application are toxicology, environmental planning, regional planning, meteorology, hydrology, soil microbiology, soil physics, plant pathology, irrigation engineering, farm management, and agricultural economics.

Design Factors – I discussed objectives of land application processes, preapplication treatment, land suitability, selection of the land application process, distribution techniques, climatic factors, storage, surface runoff control, public health considerations, and monitoring requirements.

Design Factors – II begins with a review of land application processes and factors influencing the identification and selection of land application sites. Effluent loading constraints, effluent loading design, and alternative land application components and operations are then discussed. Emphasis is given to the design of a suitable loading rate and to requirements for drainage, field investigations, monitoring systems, crop selection, irrigation schedules, and farm management.

Chapter I

LAND APPLICATION PROCESSES

Four processes have been used successfully for land-based treatment of wastewater effluents. These four processes are overland flow, irrigation, high-rate irrigation, and infiltration-percolation. Except for overland flow, all processes have been used successfully in this country for the treatment of municipal wastewater. In other countries, the overland flow process has been used successfully for domestic wastewater treatment. All four processes have been used for successful treatment of industrial wastewater, both in this country and elsewhere.

A synopsis of the processes' characteristics and their requirements is given in table I-1. The objectives and other characteristics, as well as how the applied water is dispersed, are distinctly different among the four processes. The quality of the water after treatment also varies among the processes and is a function of soil characteristics, crop type, system management, and especially loading rate. Loading rates and land area requirements overlap for the different processes.

Factors such as wastewater quality, climate, soil, geology, topography, land availability, and return flow quality requirements will determine which of the four processes would usually be most suitable for a particular region. The following descriptions of these processes indicate under what general conditions the processes would be feasible for municipal wastewater treatment.

OVERLAND FLOW

With the overland flow process, the wastewater is filtered and oxidized as it passes over the soil surface and through the grass cover. The land surface should have a uniform slope of 2 to 8 percent so that surface runoff will move downslope and uniformly spread over the soil surface. A cover crop, usually grass, should be grown to protect the soil from erosion and to maximize the wastewater treatment by providing surface area for biological treatment.

The overland flow process is used where soil permeability is slow and/or the groundwater table is high so the water cannot move into the soil profile. The soil surface is carefully shaped to produce the necessary uniform flow of water over the soil surface. Thus, in areas with sandy soil, adverse topography, or very shallow soils, overland flow would be eliminated from further considerations as a treatment alternative.

Because the applied water does not move through the soil profile, the overland flow process does not have the benefit of the large buffering capacity and time lag of the soil profile. This land application system is dependent on biological processes to treat the

Table I-1.—*Four land application processes for treatment of municipal wastewater*[1]

	Annual loading acre ft/ac/yr	Net irrigated land area requirement for 1-mgd flow	Objective	Soils and geologic materials	Dispersal of applied water	Impact on quality of applied water
Overland flow	5 to 25	45 to 225 ac plus buffer areas, etc.	Maximizes water treatment Crop harvest is incidental. May be used as secondary treatment of raw wastewater or advanced treatment of secondary treated wastewater.	Suitable for slow or very slow permeable soils and/or high water table conditions. Generally requires natural or constructed slopes of 2 to 8 percent.	Most water to surface runoff. Some water to evapotranspiration and very little water to percolation.	BOD and suspended solids greatly reduced. High nitrogen removal. Some phosphorous removal. Reduction of some heavy metals. Little change in total dissolved ionic solids (TDIS).
Irrigation	1 to 5	225 to 1,100 ac plus buffer areas, etc.	Maximizes agricultural production by supplying irrigation needs. May be considered a reuse option as well as advanced treatment of partially treated wastewater.	Suitable for most irrigable agricultural soils. Irrigation method will depend on soil, topography and crop.	Most water to evapotranspiration. Some water to percolation and leaching of salts. Tailwater runoff from surface irrigation can be controlled.	BOD and suspended solids almost completely eliminated. Nutrients removed by crop and soil. Heavy metals adsorbed or precipitated. TDIS concentration greatly increased by evapotranspiration. Little change in total salts (applied = leached). Increase in hardness of percolate.

Table 1-1.—*Four land application processes for treatment of municipal wastewater*[1] *(Continued)*

	Annual loading acre ft/ac/yr	Net irrigated land area requirement for 1-mgd flow	Objective	Soils and geologic materials	Dispersal of applied water	Impact on quality of applied water
High-rate irrigation	1 to 10	110 to 1,100 ac plus buffer areas, etc.	Maximizes wastewater treatment by supplying nutrients and water as needed by crop. Agricultural crops are a side benefit. In case of conflict, wastewater treatment is higher priority than crop production.	Suitable for more permeable irrigable agricultural soils. Irrigation method will depend on soil, topography, and crop. Requires good natural or constructed drainage.	Most water to percolation and evapotranspiration. Tailwater runoff from surface irrigation can be controlled. May result in buildup of groundwater mound.	BOD and suspended solids almost completely eliminated. Nutrients removed by crop and/or soil. TDIS concentration increased by evapotranspiration. Additional salts leached out of soil by excess applied water (salt loading).
Infiltration-percolation	11 to 500	2 to 100 ac plus buffer areas, etc.	Maximizes water filtration and percolation to groundwater. Crop production is not a benefit. There may not be a crop.	Suitable for highly permeable soils. Requires very good natural or constructed drainage.	Most water percolates to groundwater. Some water to evapotranspiration. No runoff. May result in buildup of large groundwater mound.	BOD and suspended solids reduced. Some nutrient removal by soil and crop. Additional salts leached out of soil by excess applied water (salt loading). Increase in hardness of percolate.

wastewater. Like all biological systems, overland flow is subject to temperature effects and shock loads. With its sensitivity to temperatures below freezing, the overland flow process may not be a feasible treatment alternative in areas with cold climate unless the wastewater can be stored for application during warm weather. To be stored, the wastewater would have to be biologically stabilized.

Because it provides only limited removal of phosphorus and heavy metals, overland flow without chemical aids as a final treatment process may not be suitable if an ultra-high level of treatment is required. Certain chemical additions such as lime or alum may improve the removal of phorphorous and heavy metals.

IRRIGATION

The objective of the irrigation process is primarily to maximize crop production. Effluent treatment and disposal are secondary benefits.

The irrigation process is a suitable treatment alternative in the rainfall-short western part of the United States where irrigation is required for optimum crop production. In areas where there is sufficient rainfall to grow crops, the irrigation treatment process could only be used for supplemental watering or during sporadic dry periods and thus probably would not be considered a viable wastewater treatment alternative.

Virtually all plant nutrients are found in municipal secondary effluent. Thus, irrigating with wastewater rather than other water could have a greater agricultural value. In some cases, the irrigation process may more appropriately be classified as a wastewater reuse alternative as well as a treatment process.

The irrigation process has the highest potential of the four land application systems for removal of most wastewater pollutants. Because of its lower loading rates, the irrigation process involves the largest land area and widest dispersal of pollutants. As a result, adverse impacts on the soil and vegetation are minimized. However, because of the high percentage of water lost to evapotranspiration, the concentration of total dissolved ionic solids (salts–TDIS) in percolate to the groundwater may be undesirable.

HIGH-RATE IRRIGATION

Unlike the irrigation process described above, high-rate irrigation is primarily a method of effluent treatment and has the side agricultural benefit of producing high-yield crops. Higher loading rates are used than with the irrigation process, and much of the water percolates below the root zone. For the best nutrient removal, crops that can remove nutrients to very low concentrations should be grown. Much of the nitrogen not removed by the crop will be leached to groundwater because of the high wastewater applications. It is necessary to select a crop that will respond to the dilute nutrients in wastewater; otherwise, chemical fertilizer may have to be added to produce the desired crop growth.

High-rate irrigation is a feasible treatment method in almost all climates. Usually, a region will have some area where land is available and where the soil, geological, and topographical conditions are suitable for high-rate irrigation.

The high-rate irrigation process has the second highest potential for removal of wastewater pollutants. Because its loading rates are considerably higher than for the irrigation process, in a given area high-rate irrigation requires less land, but the pollutant load on the land is more concentrated. Thus, the potential impact on soil and vegetation is greater than for the irrigation process.

INFILTRATION-PERCOLATION

Infiltration-percolation treats the wastewater within a minimum land area and under some conditions has the added benefit of recharging the groundwater. Wastewater is applied at high rates for several days to weeks and then is removed during a rest period so the soil profile can dry. The rest period restores the soil's infiltration and treatment capacity. A crop may be grown to help maintain infiltration rates, but harvest usually would not be an objective.

Infiltration-percolation can be used for wastewater treatment in most climates. Because this process involves high loadings, soil and geologic conditions with rapid infiltration and permeability are necessary. In areas where these conditions are not found, the infiltration-percolation process can quickly be discarded from further consideration.

The infiltration-percolation process has the lowest potential for removal of pollutants where the applied water moves through the soil-geologic profile. The capacity of soil and crops to remove nutrients at high application rates is limited. Therefore, this process may not be a feasible treatment method where there are strict limitations on discharge of nutrients into groundwater. Infiltration-percolation has been successfully used in combination with wells or other drainage to provide a good quality water for irrigation or industrial purposes.

Chapter II

FACTORS AFFECTING SITE SELECTION

The following two basic approaches are used for identifying a site for land application:

- Select a site that best fits the requirements for treatment, the location conditions, and the land application to be used.
- Utilize a site already owned or readily available, select the appropriate process, and design the system to fit the site conditions.

Normally municipalities will not already own uncommitted land where a land application system may be implemented, but because they have power of eminent domain, the site selection approach can be used. Conversely, industries do not have such power and are restricted to using land that they already own or can acquire. This section will briefly discuss some of the factors that should be considered when the site selection approach is used. Table II-1 outlines the information that may be needed and indicates possible sources for obtaining the information.

SOIL

Soil properties of the root zone (top 5 feet or to the restrictive layer) determine the suitable loading rate. The amount of land required and total project costs are inversely proportional to the loading rates. The costs for site preparation, distribution system, application system, and drainage, all costly items, are determined by the land requirements. Thus, soil properties are an important factor in identifying and selecting sites that would allow an economical land application system.

As mentioned previously, suitable soil properties differ for the land application processes. Overland flow requires an impermeable soil, while the infiltration-percolation process requires a highly permeable soil. Soils can be classified into suitability groups according to the soil properties and the application process as shown in table II-2.

Existing soil maps can often be used to evaluate and interpret the suitability of a soil for a particular use. Detailed soil maps, if available, are the most useful and accurate references. A few days of field checking by a qualified soil scientist can determine if the soil mapping is sufficiently accurate for a preliminary study and if soil groupings made from available data appear valid.

General soil association maps, particularly when they cover broad areas, should definitely be field checked before sites are selected. A soil association comprises several soil series which

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Table II-1.—*Information needs and sources for land application of wastewater*

INFORMATION NEEDS	INFORMATION SOURCE: Consultants	Municipal/Community Planning	Chamber of Commerce	NOAA, U.S. Weather Station	Library	Agricultural Extension Service	County Planning	Public Health	Assessor	U.S. Soil Conservation Service	Environmental Protection and/or Public Health	Historical Society	State Geological Survey	State Div. or Dept. of Water Resources	State University Extension Specialists	State Planning Office	Corps of Engineers	U.S. Forest Service	U.S. Geological Survey	USDA, Agricultural Research Service	U.S. Environmental Protection Agency	Planning Agency (COG, River Basin Resource Management Districts)
Climatic data				•		•									•							
Soil classification–mapping	•	•					•			•												
Soil infiltration–permeability	•					•				•					•					•		
Soil depth 0-5 feet										•												
Soil drainage and water table <5 feet										•												
Soil properties (chemical and physical)	•					•				•					•							
Agricultural land use capability	•	•				•	•			•												
Depth to bedrock										•			•						•			
Unconsolidated materials													•						•			
Bedrock type and structural characteristics													•						•			
Jointing and permeability of rock	•												•	•					•			
Rock outcrops										•			•						•			
Surface slope, categories (ex. 0-3 pct)										•									•			
Flood plain, flood hazard	•	•					•							•			•		•			
Streamflows														•					•			•
Groundwater yield	•												•	•					•			•
Groundwater elevation and contours	•												•	•					•			
Groundwater aquifers	•						•						•	•					•			•
Irrigation methods	•					•				•					•					•		
Crops	•					•				•					•			•		•		
Interpretation of soil suitability	•					•				•					•					•		
Interpretation of groundwater	•												•	•					•			
Land use		•					•		•							•						•
Land values	•	•	•			•	•		•													•
Guidelines for land application	•							•			•						•				•	
Sensitive environmental areas	•	•					•				•	•				•					•	•
Socioeconomic factors	•	•	•				•		•							•						•
Institutions (any organization)			•		•		•							•		•						•
Aesthetics		•			•		•															
Biota	•	•			•		•															•

Table II-2.—*Examples of soil suitability for land application processes*[1]

Soil group	Minimum depth	Characteristics	Irrigation	High-rate irrigation	Infiltration-percolation
1	60 in.	Deep soil of moderate to rapid permeability	Very suitable	Maximum	Moderate
2	40 to 60 in.	Moderately deep soils of moderate to rapid permeability or deep soils with moderately slow permeability	Very suitable	High	Moderate for rapid permeability
3	20 to 40 in.	Moderately deep soils of slow to moderate permeability or deep soils of slow permeability	Suitable	Moderate	Very low for slow permeability
4	Less than 20 in.	Shallow soils. Includes much of the alluvial material adjacent to streams which has a high water table.	Low suitability	Low	Maximum for rapid permeability soil
5	Less than 20 in.	Soils with slope greater than 20 percent	Unsuitable	Unsuitable	Unsuitable

Note: Overland flow was unsuitable for local conditions and requirements in this example.

are usually found in the same land area. Some small areas of other series with much different properties may occur. Wide variation between soil properties obtained from a soil association map and actual soil conditions in the field has been found. Figure II-1 is an example of a general land classification map for a sample study area. To make the map, soil associations with similar properties were grouped as shown in table II-2.

GEOLOGY AND GROUNDWATER

Geologic features below the root zone layer or restrictive layer are important for drainage of water that is not lost to evapotranspiration. The depth to bedrock and the properties of that rock should be known. For example, if the root zone is underlaid by unfractured shale at shallow depths, drainage may be severely limited, and a reduced loading rate may be necessary.

The availability of groundwater and water table depth within the area are general indicators of properties of the geologic materials. Where groundwater yields are low, permeabilities are usually restricted. Slow permeability of subsurface layers will restrict drainage and may therefore restrict loading rates, thus increasing project costs by necessitating artificial subsurface drainage. Figure II-2 is an example of a map of groundwater availability in the sample study area which can be used in site identification and selection.

A more thorough process for site selection, based on a detailed inventory of hydrogeologic conditions, was discussed in a paper by Bond, Williams, and Shadid (1972).[2] When data on depth, permeability, and groundwater elevations are available, a hydrogeologist can estimate the natural drainage capacity of an area, the groundwater movement, and the need for artificial subsurface drainage. If the required data are not available from existing information, a preliminary field investigation may be necessary to evaluate relative differences for potential sites.

LAND USE

Land use information is usually available from local and regional planning agencies. Areas committed for various uses should be identified and indicated on a map. The remaining areas would be available for land application. Figure II-3 shows a land use map for the sample study area which could be used for site identification purposes.

SENSITIVE ENVIRONMENTAL AREAS

Sensitive environmental areas should also be identified and plotted on a map. Examples of environmentally sensitive areas are historical sites; unique environments for plants, animals, or water species; and unique geologic features. Figure II-4 is a map of typical critical environmental areas in the sample study area.

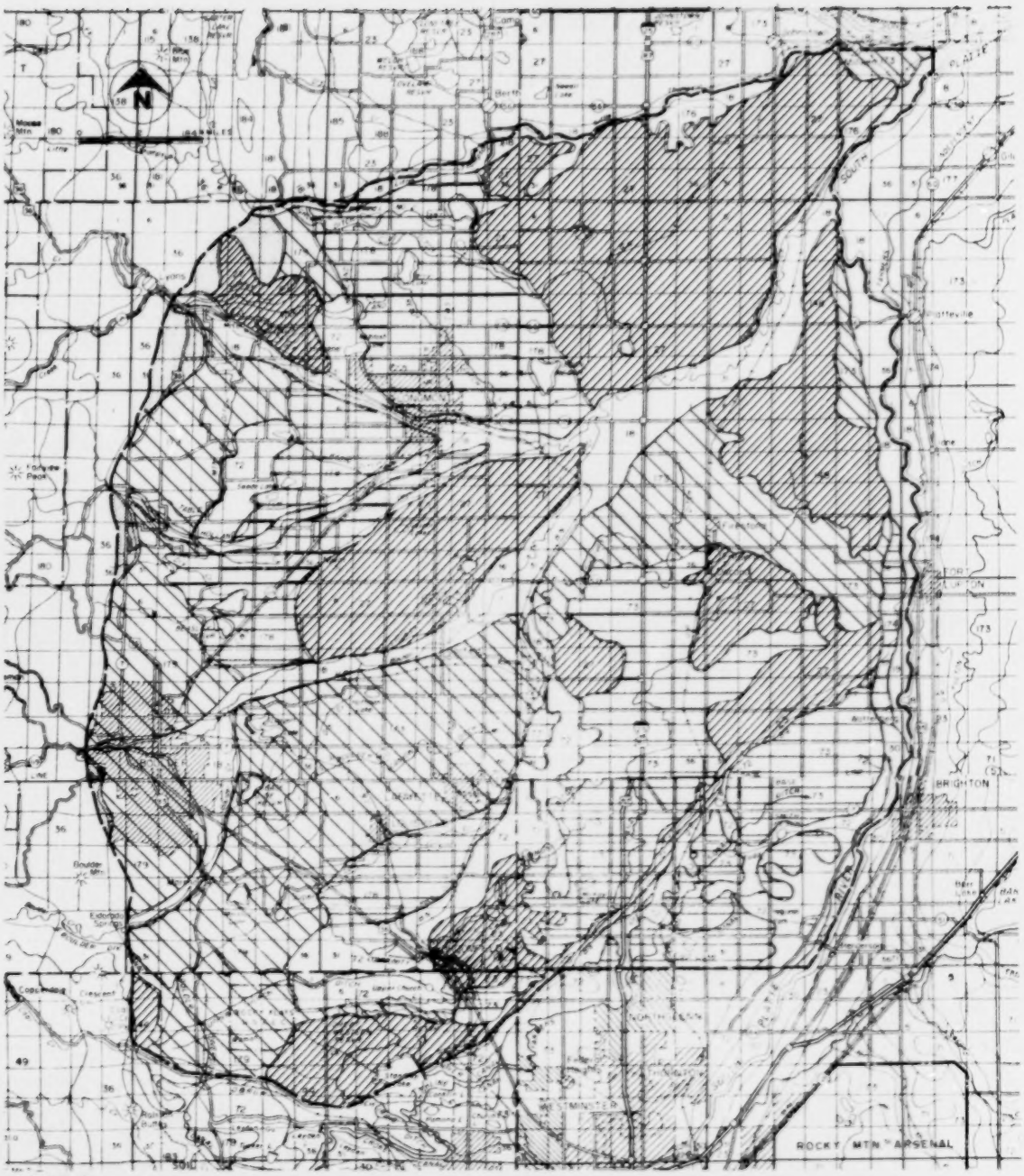


Figure II-1. General soil groups.[1]

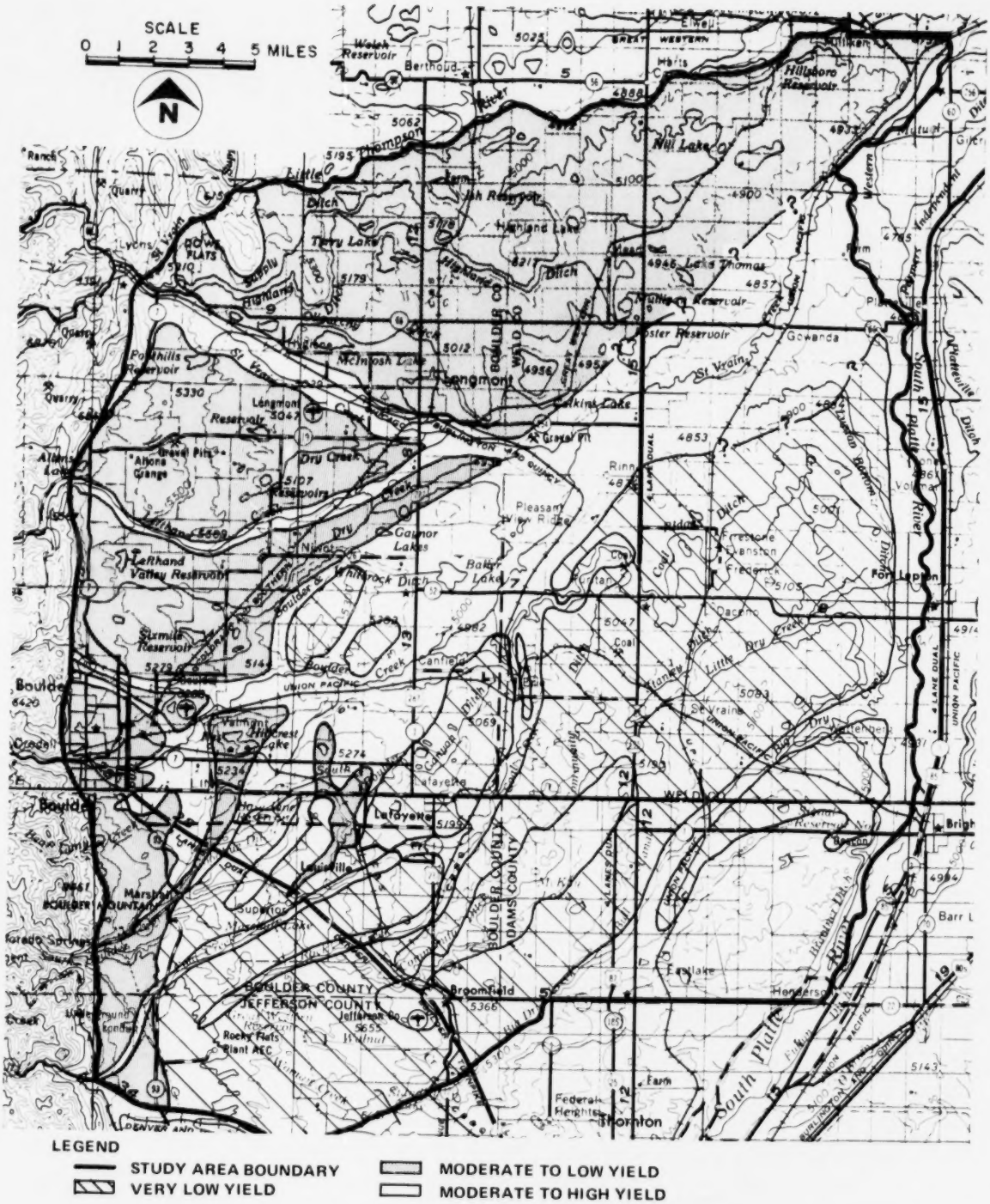
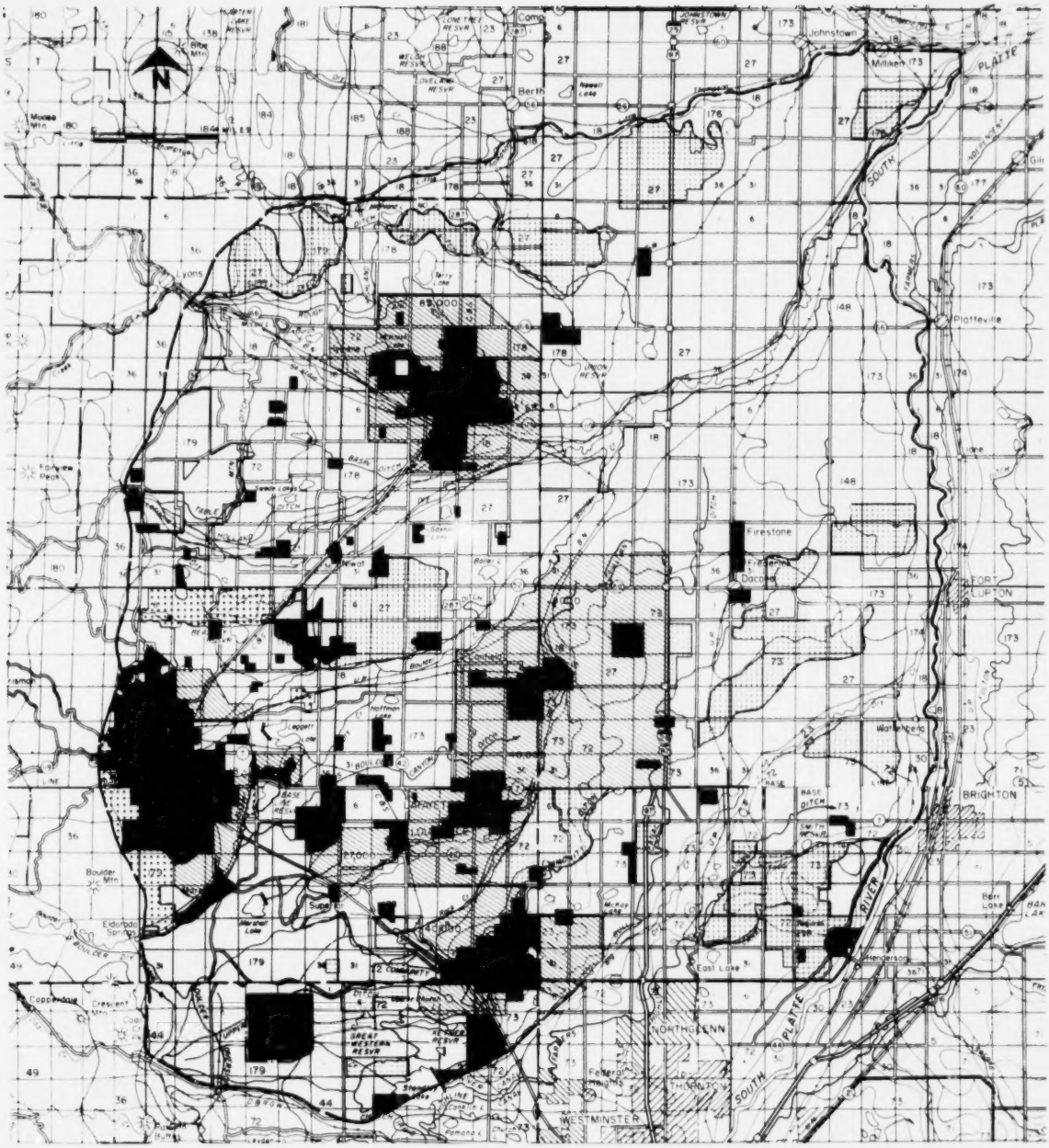


Figure II-2. Groundwater availability.[1]



LEGEND

- URBAN AND SUBDIVISION
- PROJECTED URBAN DEVELOPMENT FOR 1990 (BOULDER AREA GROWTH STUDY COMMISSION)
- DRYLAND AGRICULTURE
- RANGE LAND
- RECREATION AND WOODLAND
- IRRIGATED AGRICULTURE

Figure II-3. Land use.[1]

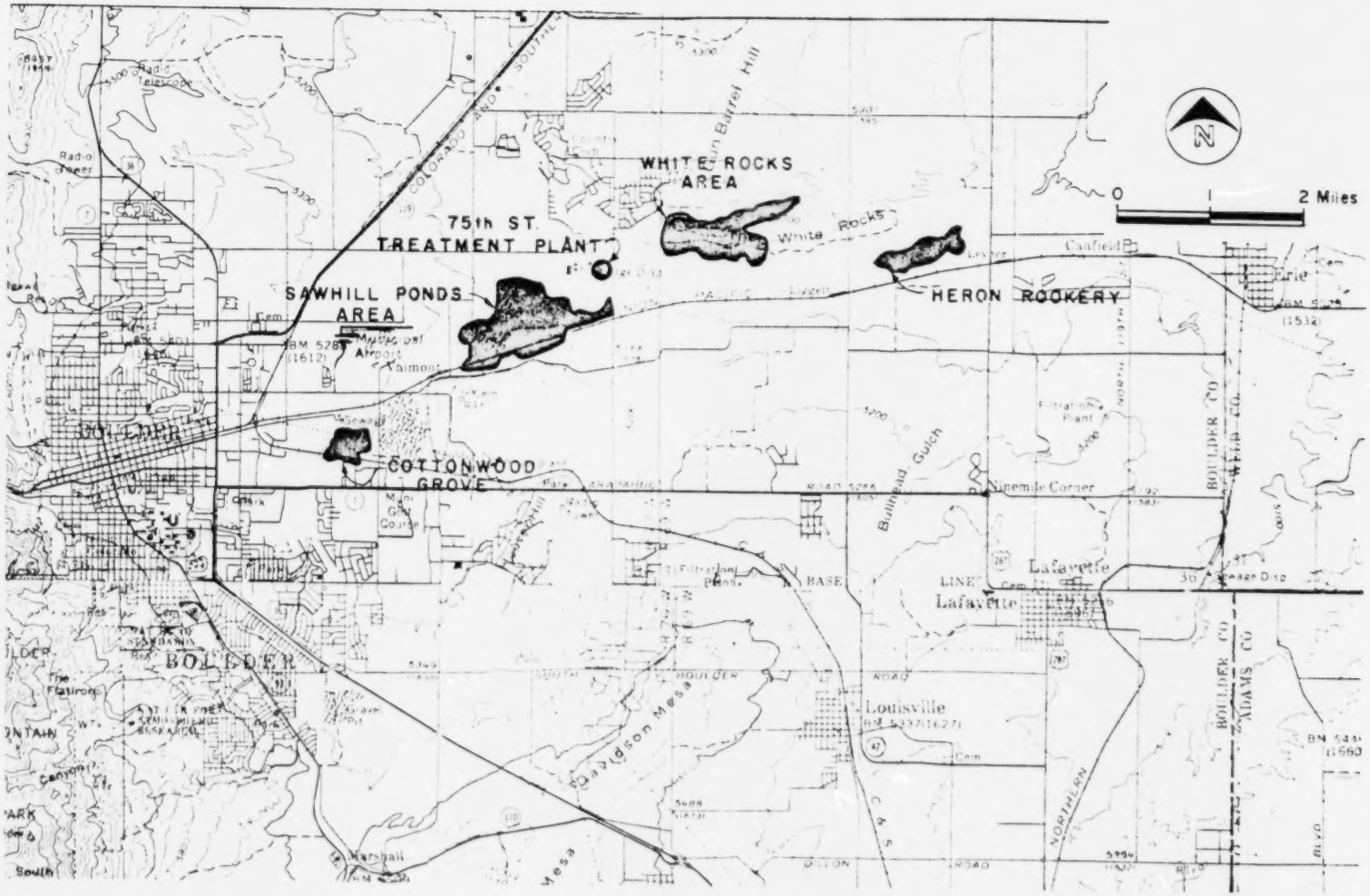


Figure II-4. Sensitive environmental areas.[1]

WATER RIGHTS

In the United States, water laws governing the right to withdraw surface water fall into three general classifications: 1) land ownership—common law or riparian rights, 2) appropriative rights, and 3) a combination of the two. These distinct divisions in water law have developed in relationship to the surplus and deficiency of water, as shown in figure II-5. Water surplus areas are areas where the precipitation exceeds the evapotranspiration and results in runoff and streamflow. Water deficient areas are areas where evapotranspiration exceeds precipitation and little annual runoff occurs.

Simply stated, the land ownership or riparian doctrine says that the owner of land along a stream is entitled to unreduced flow and undiminished quality. Thus, water may be taken from the stream and used but must be returned. Since, in areas of surplus water, only a small portion of wastewater would be lost to evapotranspiration by land application, there would probably be no water rights problems associated with land application of effluents where riparian rights are in force.

The appropriative doctrine dedicates the waters to the public. State laws differ, but in general a right to the use of water is obtained by putting the water to use after or while filing for the right. The first person who puts water to beneficial use receives senior rights. Subsequent appropriators are called junior appropriators and must not damage senior rights in

Figure II-5. Dominant water rights doctrines.[3]

times of short water supply. Thus, appropriated rights have a priority value based on the principle of "first in time, first in right." Appropriated water rights are property and may be bought, sold, exchanged, or transferred.

Where water use is highly developed in deficient areas, water rights would probably be required for a land application wastewater treatment system. Land application on presently unirrigated land would result in increased evapotranspiration (consumptive use), which would decrease streamflows. Downstream water rights would be damaged by this action, and it might be necessary to appropriate or purchase water rights to ensure a continued land application system.

In water-deficient areas, the total loss of wastewater to evapotranspiration would be inversely proportional to the loading rate. If the irrigation process is used to supply water according to crop needs, losses to evapotranspiration would typically be greater than 50 percent of the wastewater. Evapotranspiration losses for the overland flow, high-rate irrigation, and infiltration-percolation processes would probably be, respectively, 10 to 20 percent, 15 to 30 percent, and less than 10 percent of the applied water.

In some western streams, normal summer flows were fully appropriated by 1880. In these cases, any right junior to that time can be called out so that senior rights can receive their water. In those areas where unappropriated water does not exist in the stream, a water right or replacement water would be necessary to ensure successful land treatment without damage to senior rights. Where unappropriated water still exists in the stream, obtaining a right for land application of effluent should be little problem.

The status of water rights in the local area should be investigated to avoid potentially serious legal problems later. If water rights are required, the expense and quantity of the right can be controlled to some extent in the process and site selection. For instance, if presently irrigated land is selected as the application site, it would be possible to purchase the water right with the land and make any necessary transfers. If a water right is necessary for only the portion of water consumptively used, it may be desirable to select the process which would minimize the evapotranspiration. A consultant familiar with water law and water resources can determine the legal implication of land application and the extent of replacement required.

LAND APPLICATION PROCESS

As noted above, certain soil and geologic characteristics are particularly suited for each of the land application processes. Table II-2 shows that a soil group highly suited to one process may be poorly suited to another process. Thus, it is necessary to eliminate those processes which are not feasible for the local conditions and requirements. Then the areas with soil and surface geology most suited to the remaining processes can be identified.

TOPOGRAPHY

Slopes up to 15 percent and 5 percent can usually be used, respectively, for sprinkler and surface irrigation of cultivated crops. Slopes of up to 30 percent can often be adapted to

sprinkler irrigation where noncultivated crops are grown. Increasing slopes reduce the infiltration rates and place restrictions on surface and sprinkler irrigation. The overland flow process on sod-covered ground requires slopes of 2 to 8 percent. In mountainous areas, topographic restrictions are more of a problem. In general, topography may be a limiting factor where low water infiltration into the soil can result in runoff and soil erosion. Topographic maps, field studies, and aerial photography of potential application sites would identify areas with slopes suitable for each process and application method.

POLITICAL BOUNDARIES AND LAND OWNERSHIP

Political boundaries such as county or state lines may restrict site identification. Given enough time and money, political boundaries may be crossed, but for expediency these boundaries should be taken into consideration during site identification and selection.

Land ownership is another political boundary that must be recognized. Getting a right to the use of public land from the Forest Service or Bureau of Land Management could involve considerable time and negotiation. A land ownership map is very useful to locate properties to be avoided or large areas of only a few ownerships. If land ownership is in small parcels, the time and costs involved in acquiring the land are increased.

Chapter III

IDENTIFYING AND SELECTING SITES

The following steps can be used by municipalities to select land application sites for detailed study:

- Establish criteria for identifying potential sites.
- Identify potential sites.
- Establish criteria for evaluating potential sites.
- Select sites for further study.

By following these steps, the municipality can narrow down the number of alternative sites for more detailed investigation. The city must determine the relative weight of such considerations as environmental impact, cost, and public acceptance.

The factors affecting site selection discussed in chapter II for which criteria are established may be taken into consideration in several ways during site identification and selection. One relatively unbiased approach is to prepare a series of transparent map overlays showing areas of exclusion. These transparencies can then be placed over a base map of the same scale. The areas of no exclusion or where exclusions are fewest are then selected as potential sites. This process is time consuming and may not be justified. In addition, factors such as soil and geological conditions are often too varied and difficult to show only as areas of exclusion.

Another approach is to identify three to five categories of land suitability as determined from a general soil association map. Areas of exclusion because of committed land use, sensitive environment, unsuitable topography, or political boundaries may be shown on the same map. The result is a fairly quick and reasonably unbiased method of arriving at potential areas. Figure III-1 is a typical composite map made from combining the land suitability map with the map of committed areas for the sample study area.

CRITERIA FOR POTENTIAL AREA IDENTIFICATION

To help eliminate the possibility of bias in selecting potential sites, criteria should be established for the identification of suitable areas. Some possible criteria are as follows:

- Site should not conflict with present land use and should reinforce the adopted land use plans.

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Figure III-1. Composite site selection map.

- Site should not endanger sensitive environmental areas such as historical sites or rare or endangered plant or animal species.

- Site should minimize adverse socioeconomic impacts. The density of dwellings, other structures, and roads that would be affected must be considered.

- Preference should be given to the soil groups most suited for the process being considered.

- Areas where geological conditions and groundwater availability would adversely affect the process being considered should be avoided.

- Political or legal boundaries should be noted.

These criteria are only a few that may be used to identify areas potentially suited to a land application process. Criteria appropriate to the particular area or municipality should be used. Without some logical procedure to identify suitable areas, the city, EPA, or public may object to the site selected and thus delay development of the land application project and/or increase project costs.

POTENTIAL SITES

Once the criteria for identifying potential sites are established and maps have been prepared showing the factors judged most critical, the identification of potential sites is a simple process. Areas that meet all or most of the established criteria can be outlined on a map as shown on figure III-2 for the sample study area. Sites A through J were identified for the irrigation and high-rate irrigation processes. Sites HR-1 and HR-2 were identified for the infiltration-percolation process. For the sample study area, overland flow was not suitable for local conditions and requirements.

SITE EVALUATION AND SELECTION

Once the potential land application sites have been identified for a specific process, a more in-depth comparison of the sites can be made. Section C of the new EPA report, *Evaluation of Land Application Systems* (1975),[4] discusses criteria which may be valuable for evaluating potential sites. A few of the more important criteria follow:

- Location–Evaluate the site location with respect to the wastewater source, discharge point, transport route, and length; the elevation difference between the site and the water source; and the need for a storage area.

- Land availability and cost–Consider land ownership of the potential site, number of owners, and associated land values.

- Environmental impact–Analyze the potential impact on both the natural and socioeconomic environment.

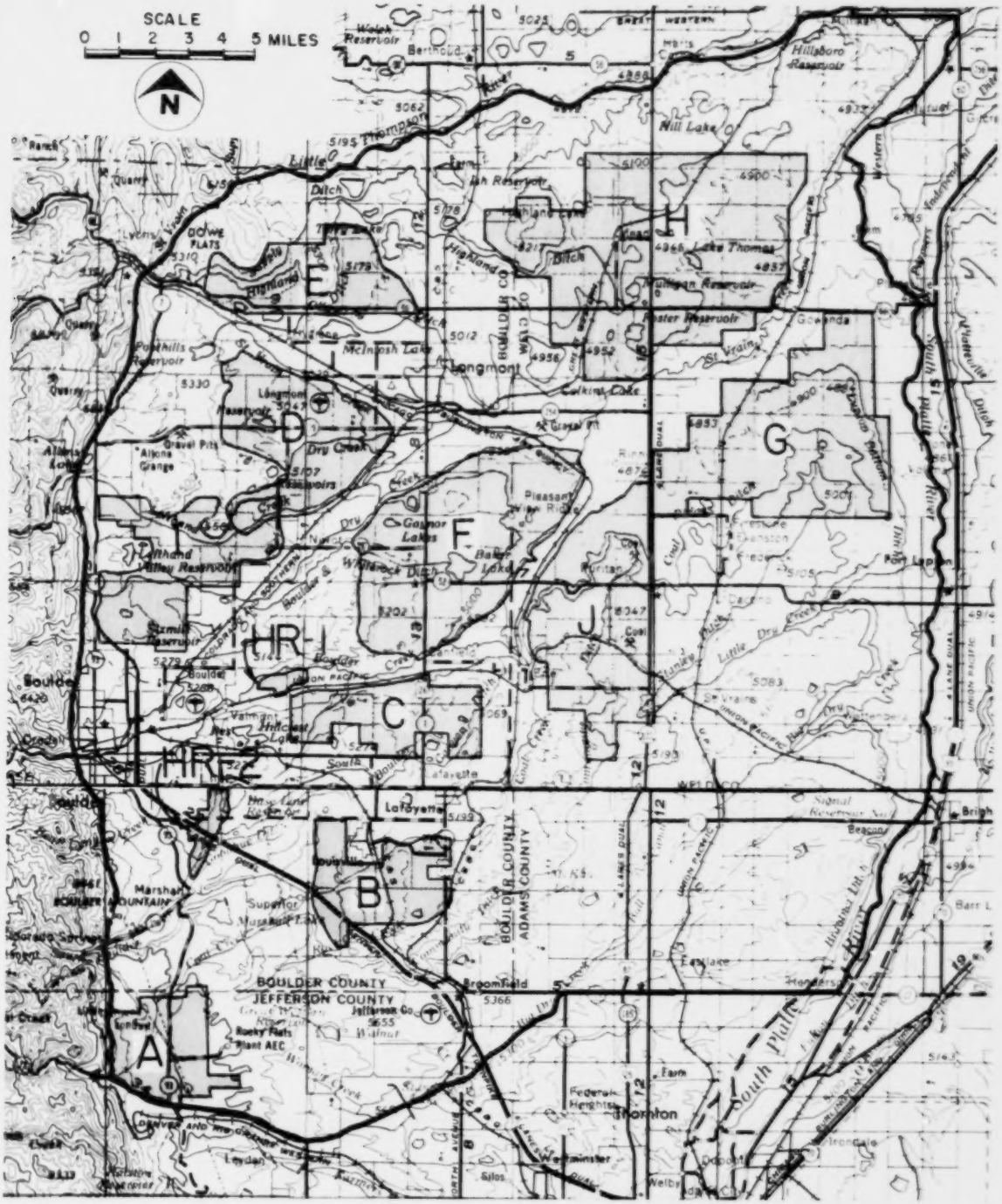

Figure III-2. Potential land application sites.

- Loading capacity and area required–Evaluate the suitable loading rate and land area requirement.

- Site treatment capacity and expansion–Define the total treatment capacity of the proposed site and additional area for future expansion.

- Water rights–Identify possible alternatives for resolving potential water rights problems.

- Water quality–Analyze the impact on receiving groundwater aquifers or streams by land application on the proposed site.

If many sites are being compared, a table such as table III-1 showing a comparison of many of the criteria for the sample study area may be helpful. Ideally, a citizens group in the local area should participate in the site selection. If representatives of the municipality and local residents are involved in key parts of a wastewater treatment study such as site selection and the treatment process, the site selected will be the most viable in respect to local problems and priorities. By involving the public throughout the study, the need to make changes after the study is completed can be minimized.

Table III-1.—*Comparison of potential sites on figure III-2*[1]

Site	Approximate cross area (acres)	Estimated treatment capacity (mgd)	Area of site presently irrigated (percent)	Distance from plant (feet)	Elevation difference from plant (feet)	Homes onsite (no.)	Other buildings onsite (no.)	Roads onsite (miles)	Comments—major problems or advantages
A	5,100	11	5	65,000	1,080	5	14	12.2	Outside of NCWCD boundary. Little or no irrigation. Canals pass through area. Poor soil, low loading rates.
B	5,800	20	90+	31,000	280	81	126	25.7	Outside of NCWCD boundary. Possible storage in Baseline Reservoir or Marshall Lake (15,700 ac ft). Return flows return to Boulder Creek via Coal Creek. Most of site overlies abandoned coal mines.
C	4,500	19	70	8,000	105	133	127	19.0	Outside of NCWCD boundary. Ditches flow through area. Requires separate distribution system. Possible storage in Valmont and Baseline Reservoirs (11,300 ac ft). Return flows return to Boulder Creek.
D	4,800	17 Could be enlarged	90	35,000	-45	53	55	13.1	No good storage reservoir. Transfer outside of watershed area. Entirely within NCWCD boundary. Ditches terminate within area.
E	5,000	14	80	74,000	130	196	104	24.4	Totally within NCWCD boundary. Transfer outside of watershed area. Supply ditch and rough and ready ditch could benefit from a more firm water supply. Ditches do not terminate within this site.

Table III-1.—*Comparison of potential sites on figure III-2*[1] *(Continued)*

Site	Approximate cross area (acres)	Estimated treatment capacity (mgd)	Area of site presently irrigated (percent)	Distance from plant (feet)	Elevation difference from plant (feet)	Homes onsite (no.)	Other buildings onsite (no.)	Roads onsite (miles)	Comments—major problems or advantages
F	14,300	50	75	20,000	-70	215	170	54.3	Panana No. 1 Reservoir is a good potential storage site (approx. 7,000 ac ft). Part of return flows return to Boulder Creek. Ditches terminate within area.
G	17,600	61	90	70,000	-245	254	306	52.3	Irrigation water supplied from Boulder Creek and South Platte River. Water rights exchanges may become complex. Ditches do not terminate within the site. Numerous water supply canals flowing in all directions.
H	28,000	61	80	65,000	-120	341	362	85.1	Several lakes in area. Transfer outside of watershed area.
I	9,600	20	75	32,000	230	245	46	25.0	Portion of site is city greenbelt. Small portion of site outside of NCWCD boundary. Part of site outside of watershed area. Part of site above Boulder water supply reservoir. No storage reservoir except Boulder Reservoir.

Table III-1.*Comparison of potential sites on figure III-2*[1] *(Continued)*

Site	Approximate cross area (acres)	Estimated treatment capacity (mgd)	Area of site presently irrigated (percent)	Distance from plant (feet)	Elevation difference from plant (feet)	Homes onsite (no.)	Other buildings onsite (no.)	Roads onsite (miles)	Comments—major problems or advantages
J	13,500	39	65	62,000	-20	154	37	44.0	Majority of site outside of NCWCD boundary. Ditches do not terminate within the area. Portion of site overlies abandoned coal mines. Portion of return flows return to Boulder Creek. Part of site outside of watershed area.

Chapter IV

EFFLUENT LOADING CHARACTERISTICS

Once suitable sites have been identified as described in chapter III, they can be compared for selection of the best site for a chosen land application process. The comparison would probably be made on the basis of costs and environmental impacts. Because the effluent loading rate has a major influence on both cost and environmental impact, loading restrictions must be considered.

For each of the previously described land application processes, the effluent loading rate may be limited by any of several constraints. The process of water moving into and through the soil depends on the soil's capacity for infiltration-percolation. Thus, these soil properties can restrict loading rates. Limits placed on composition of deep percolation to groundwater or of return flow to surface streams may also result in a constraint on the loading rate or may require higher levels of pretreatment. Another possible loading rate constraint is the finite capacity of the soil-crop system to remove various pollutants. The following parameters may be limiting for a given situation:

- Infiltration capacity of the soil
- Permeability of the root zone and underlying geologic materials
- Soil and plant capacity to remove major plant nutrients (nitrogen and phosphorus)
- Soil capacity to filter and assimilate suspended solids
- Soil capacity to remove and oxidize BOD and COD
- Soil capacity to remove and assimilate inorganic chemicals (heavy metals, specific ions, salts, etc.)
- Discharge requirements to groundwater and surface water
- Climatic influences such as precipitation, evapotranspiration, and growing season

Several major effluent loading constraints are discussed in the following paragraphs.

INFILTRATION

Infiltration is the movement of water into the soil surface. The rate of infiltration is dependent on soil properties, crop cover, and slope, as shown in figure IV-1. The higher the

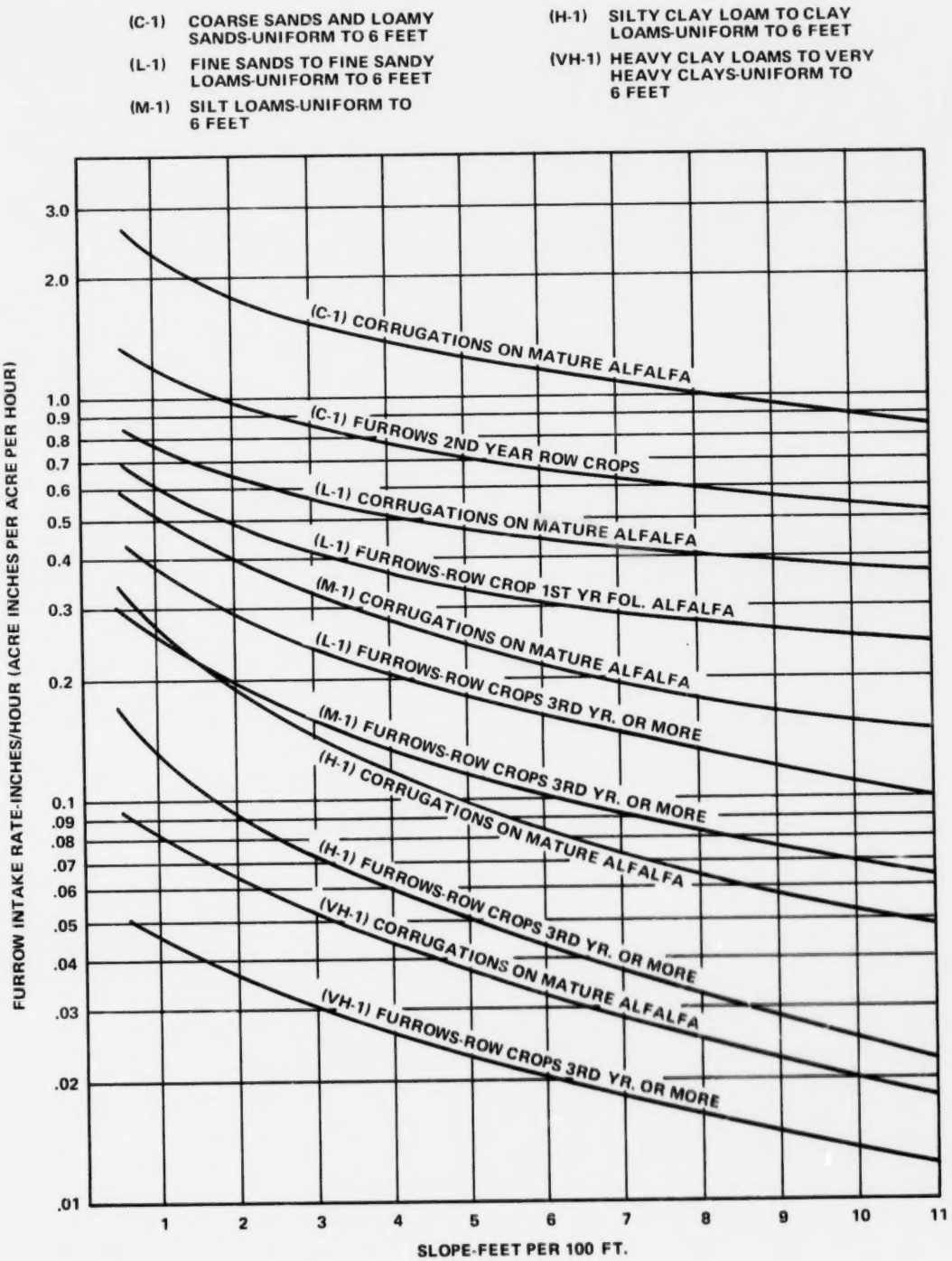

Figure IV-1. Average seasonal intake rates by furrows for various soil types, crop cover, and slope conditions.[5]

initial soil moisture content, the lower the infiltration capacity, and infiltration rates decrease over time as the water application continues. A rest period from application allows the soil to dry and restores the soil's infiltration capacity. Also, infiltration may just be vertical (downward), as with most irrigation designs, or it may be both vertical and lateral, as with a furrow irrigation design.

Selection of land application processes will be influenced by the soil's infiltration capacity. The infiltration capacity of the soil will also help determine the application rate, distribution design, and operating schedule. However, except for the infiltration-percolation process, constraints other than infiltration would limit the total seasonal application.

Steep slopes, previous erosion, and lack of dense vegetation will reduce the infiltration capacity and necessitate a reduced design application rate. The application rate for sprinkler irrigation must not exceed the infiltration rate under the most restrictive conditions or runoff will result. General ranges of sprinkler application rates for various soil types and slopes are given in table IV-1.

The infiltration rates shown in figure IV-1 for furrows and in table VI-1 for sprinklers are usually adequate for preliminary planning in the absence of field measurements. However, in unusual circumstances or more detailed planning, it may be necessary to obtain specific field data on infiltration. When detailed information is required, cylinder, furrow, or sprinkler infiltration tests can be made. Because of inherent differences between these test methods, it is necessary to use the test appropriate to the irrigation method to be used. Prior to final design, detailed field investigations, possibly including some pilot studies, should be made.

PERMEABILITIES OF SOIL AND GEOLOGIC MATERIALS

When water has infiltrated the soil, movement through the root zone to the groundwater depends on vertical permeability, and the movement of groundwater depends on lateral permeability. The permeability in these two directions may be quite different for some soils. The permeability of the soil in a vertical direction will determine the total excess water (precipitation plus effluent less evapotranspiration) that can percolate through the soil to the groundwater. The permeability of the soil and surface geology in a horizontal direction will determine the extent of the groundwater mound (which is discussed later) beneath a land application system.

Aeration of the root zone is important to most agricultural crops and thus is required in a well-operated irrigation or high-rate irrigation process. Most agricultural crops show adverse effects from inadequate oxygen at air contents less than 10 percent of soil volume. Virtually no oxygen diffusion occurs during and following the water application until the soil has drained. Drainage requires a few hours for coarse textured soil to several days for fine textured soil. Oxygen diffusion rates increase approximately linearly as the water saturation percentage decreases.[6] An oxygen diffusion rate of 0.2 mg/cm^2/minute is considered a lower limit for most crop growth.[7] An example of the change in oxygen diffusion rate with time and depth for one soil condition is shown in figure IV-2.

Soil permeability is the major factor determining the time required for the soil to re-aerate after water is applied. Soil with slow permeability requires a much longer rest period to allow aeration of the soil profile. The rest periods must be long enough to allow CO_2 to

Table IV-1.—*Typical ranges of infiltration rates and available soil moisture by soil type*[5,8,9]

	Available soil moisture storage[a]		Good condition base soil basic infiltration rates[b]		
			Slope		
	Range (in./ft)	Average (in./ft)	0-3 percent (in./hr)	3-9 percent (in./hr)	9+ percent (in./hr)
Very coarse textured sands and fine sands	0.50–1.00	0.75	1+	0.7+	0.5+
Coarse textured loamy sands and loamy fine sands	0.75–1.25	1.00	0.7–1.5	0.50–1.00	0.40–0.70
Moderately coarse textured sandy loams and fine sandy loams	1.25–1.75	1.50	0.5–1.0	0.40–0.70	0.30–0.50
Medium textured very fine sandy loams, loams, and silt loams	1.50–2.30	2.00	0.3–0.7	0.20–0.50	0.15–0.30
Moderately fine textured sandy clay loams and silty clay loams	1.75–2.50	2.20	0.2–0.4	0.15–0.25	0.10–0.15
Fine textured sandy clays, silty clays, and clays	1.60–2.50	2.30	0.1–0.2	0.10–0.15	<0.10

[a]Storage between field capacity (1/10 to 1/3 ATM) and wilting point (15 ATM).

[b]For good vegetative cover, these rates may increase by 25 to 50 percent. For poor surface soil conditions, these rates may decrease by as much as 50 percent.

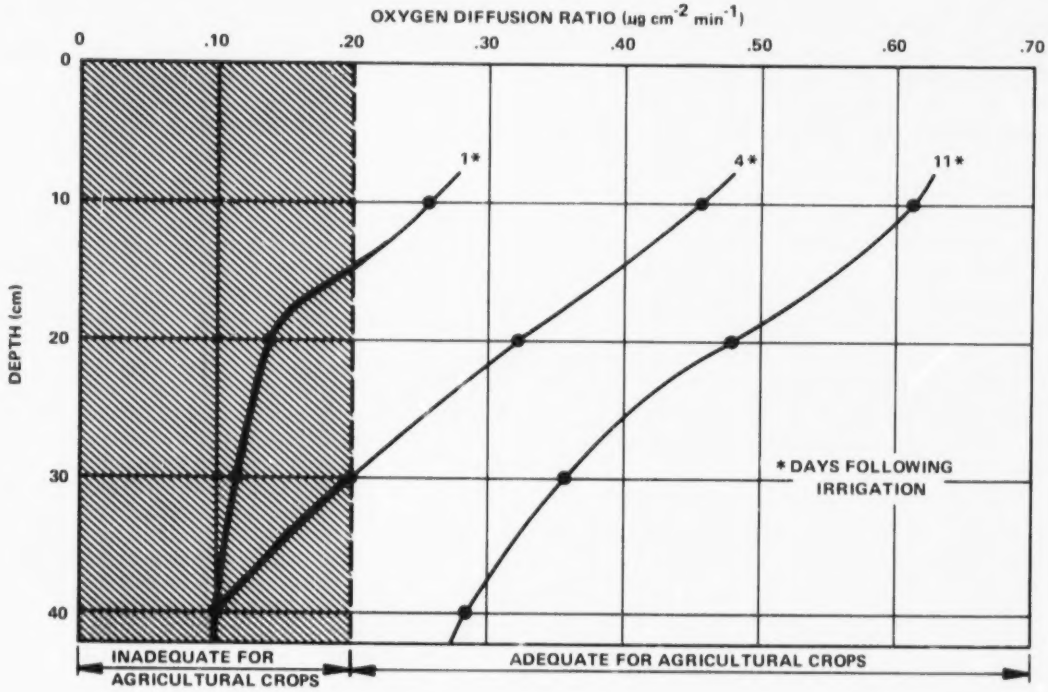

Figure IV-2. Oxygen diffusion rate (ODR) as a function of soil depth on various days following irrigation in cotton field.[10]

escape and O_2 to diffuse into the soil profile. The length of rest time necessary is also dependent primarily on the soil profile, climate, crop growth, and biological activity.

For the irrigation and high-rate irrigation processes, at least 3 to 4 feet of aerated soil is recommended to provide sufficient soil material to treat the applied effluent and allow crop growth. The capillary fringe, the layer above the water table saturated by capillary actions, also restricts aeration. Thus, the water table should be at least 5 feet below the soil surface.

The overland flow process, which utilizes a daily loading and soils of slow permeability, will produce anaerobic soil conditions most of the time. The anaerobic soil will result in a slower permeability and require selection of a plant tolerant to wet anaerobic soil conditions.

The infiltration-percolation process will develop an anaerobic condition a few days after loading is started. This anaerobic condition will promote high rates of denitrification in the soil. During the rest period, the soil will drain and aerobic conditions will be restored. If a crop is grown, it should be tolerant to standing water and periodic anaerobic soil conditions. A water table depth greater than 5 feet is often suggested for the infiltration-percolation process.

Soil permeabilities are less for wastewater than for clear water. The average permeability for Flushing Meadows has been about one-half that for clear water. Permeabilities for wastewater under other conditions have been reported as low as 10 percent of the clear water value. Effluent should be used for field measurements of permeability if at all possible. If

effluent cannot be used, the design should be based on a reduction factor which would vary with water quality and soil conditions. Once the permeability is known, the excess water and effluent loading can be established.

Figure IV-3 shows maximum excess water loading rates for high-rate irrigation based on a 2-day load and removal of 30 percent of the available water holding capacity by evapotranspiration between loadings for a 4-foot deep soil. Maximum excess water loading rates for infiltration-percolation based on loading 50 percent of the time are also shown in figure IV-3. As indicated in figure IV-3, these values are suggested maximums with uniform deep soil conditions. The actual excess water should be reduced as temperature decreases and soil profile conditions are less than ideal. Definition of the actual loading rate will be discussed further in Chapter 5.

The natural drainage capacity of the underlying geologic material depends on the permeability, the depth of wetted materials, and the hydraulic gradient.[6,11] An analysis of the groundwater drainage capacity and of the need for artificial drainage should be made for evaluation of land application sites. Even though permeability may seem adequate, a site with a low gradient and shallow wetted depth may still require artificial drainage. The extreme high water table for a wet year would be expected to be maintained or exceeded if effluent is applied.

Effluent loadings will increase excess water percolation to the groundwater and a groundwater mound will develop, as figure IV-4 shows. Accurate prediction of groundwater levels will usually require detailed information of permeabilities and depths of various strata. To obtain details of the various strata as shown in figure IV-3, field investigations and input from a hydrogeologist may be required. Selection of a wet year hydrology for design will eliminate the possibility of requiring a reduction in effluent loading under this condition.

The buildup of the groundwater mound in relation to the soil surface should be known. Figure IV-5 shows the rate of mound formation for the figure IV-4 site on dune sand. The lag in years is the travel time as water moves from the surface to the groundwater.

For complex conditions, a groundwater model may be required for accurate prediction of groundwater conditions. With maximum loading, drainage of the groundwater is critical if the water is naturally shallow or if a groundwater mound will reach the surface. With artificial drainage, the drains must be spaced and sized to remove the volume of water percolated so the 5-foot aerated zone will not become waterlogged.

As indicated earlier, excess water is determined by subtracting evapotranspiration from precipitation and adding wastewater loading. The precipitation and evapotranspiration (ET) rates for the sample study area (figure III-2) are shown in figure IV-6. By subtracting evapotranspiration from precipitation, a curve showing changes in soil moisture is obtained, as shown in figure IV-7. Negative values are depletions in soil water storage. These depletions are analogous to squeezing water out of a sponge, while positive values are like refilling the sponge to the limit of its water-holding capacity. As excess water is available, it drains out of the soil profile much as excess water would drain out of a sponge. Each month effluent is applied, there is excess water available, as shown in figure IV-7. The objective is to have approximately the same amount of excess water each month (8.5 inches/month for figure IV-7).

Frequency of recurrence for evapotranspiration, design wastewater flows, and precipitation should be considered when developing a design loading. Pilot work or field measurements may be used to verify the assumptions about permeability and loadings. A detailed field

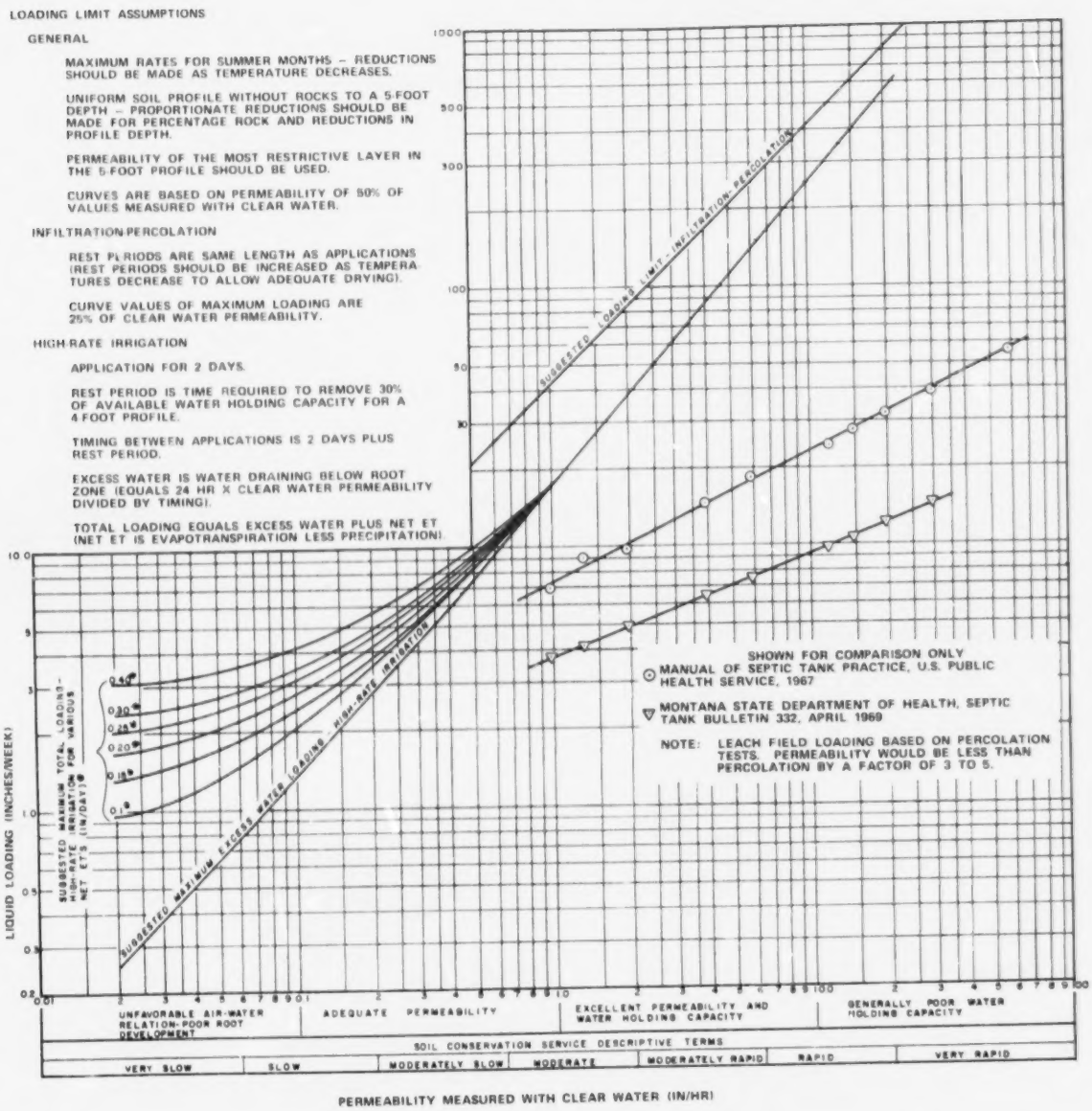
LOADING LIMIT ASSUMPTIONS
GENERAL
MAXIMUM RATES FOR SUMMER MONTHS – REDUCTIONS SHOULD BE MADE AS TEMPERATURE DECREASES.
UNIFORM SOIL PROFILE WITHOUT ROCKS TO A 5-FOOT DEPTH – PROPORTIONATE REDUCTIONS SHOULD BE MADE FOR PERCENTAGE ROCK AND REDUCTIONS IN PROFILE DEPTH.
PERMEABILITY OF THE MOST RESTRICTIVE LAYER IN THE 5-FOOT PROFILE SHOULD BE USED.
CURVES ARE BASED ON PERMEABILITY OF 50% OF VALUES MEASURED WITH CLEAR WATER.
INFILTRATION-PERCOLATION
REST PERIODS ARE SAME LENGTH AS APPLICATIONS (REST PERIODS SHOULD BE INCREASED AS TEMPERATURES DECREASE TO ALLOW ADEQUATE DRYING).
CURVE VALUES OF MAXIMUM LOADING ARE 25% OF CLEAR WATER PERMEABILITY.
HIGH-RATE IRRIGATION
APPLICATION FOR 2 DAYS.
REST PERIOD IS TIME REQUIRED TO REMOVE 30% OF AVAILABLE WATER HOLDING CAPACITY FOR A 4-FOOT PROFILE.
TIMING BETWEEN APPLICATIONS IS 2 DAYS PLUS REST PERIOD.
EXCESS WATER IS WATER DRAINING BELOW ROOT ZONE (EQUALS 24 HR X CLEAR WATER PERMEABILITY DIVIDED BY TIMING).
TOTAL LOADING EQUALS EXCESS WATER PLUS NET ET (NET ET IS EVAPOTRANSPIRATION LESS PRECIPITATION).
SUGGESTED LOADING LIMIT – INFILTRATION-PERCOLATION
SUGGESTED MAXIMUM EXCESS WATER LOADING HIGH-RATE IRRIGATION
SUGGESTED MAXIMUM TOTAL LOADING – HIGH-RATE IRRIGATION FOR VARIOUS NET ET'S (IN/DAY)
0.45
0.30
0.25
0.20
0.15
0.1
SHOWN FOR COMPARISON ONLY
MANUAL OF SEPTIC TANK PRACTICE, U.S. PUBLIC HEALTH SERVICE, 1967
MONTANA STATE DEPARTMENT OF HEALTH, SEPTIC TANK BULLETIN 332, APRIL 1969
NOTE: LEACH FIELD LOADING BASED ON PERCOLATION TESTS. PERMEABILITY WOULD BE LESS THAN PERCOLATION BY A FACTOR OF 3 TO 5.
LIQUID LOADING (INCHES/WEEK)
UNFAVORABLE AIR-WATER RELATION-POOR ROOT DEVELOPMENT
ADEQUATE PERMEABILITY
EXCELLENT PERMEABILITY AND WATER HOLDING CAPACITY
GENERALLY POOR WATER HOLDING CAPACITY
SOIL CONSERVATION SERVICE DESCRIPTIVE TERMS
VERY SLOW
SLOW
MODERATELY SLOW
MODERATE
MODERATELY RAPID
RAPID
VERY RAPID
PERMEABILITY MEASURED WITH CLEAR WATER (IN/HR)

Figure IV-3. Suggested maximum loading rate versus measured permeability for high-rate irrigation and infiltration-percolation.

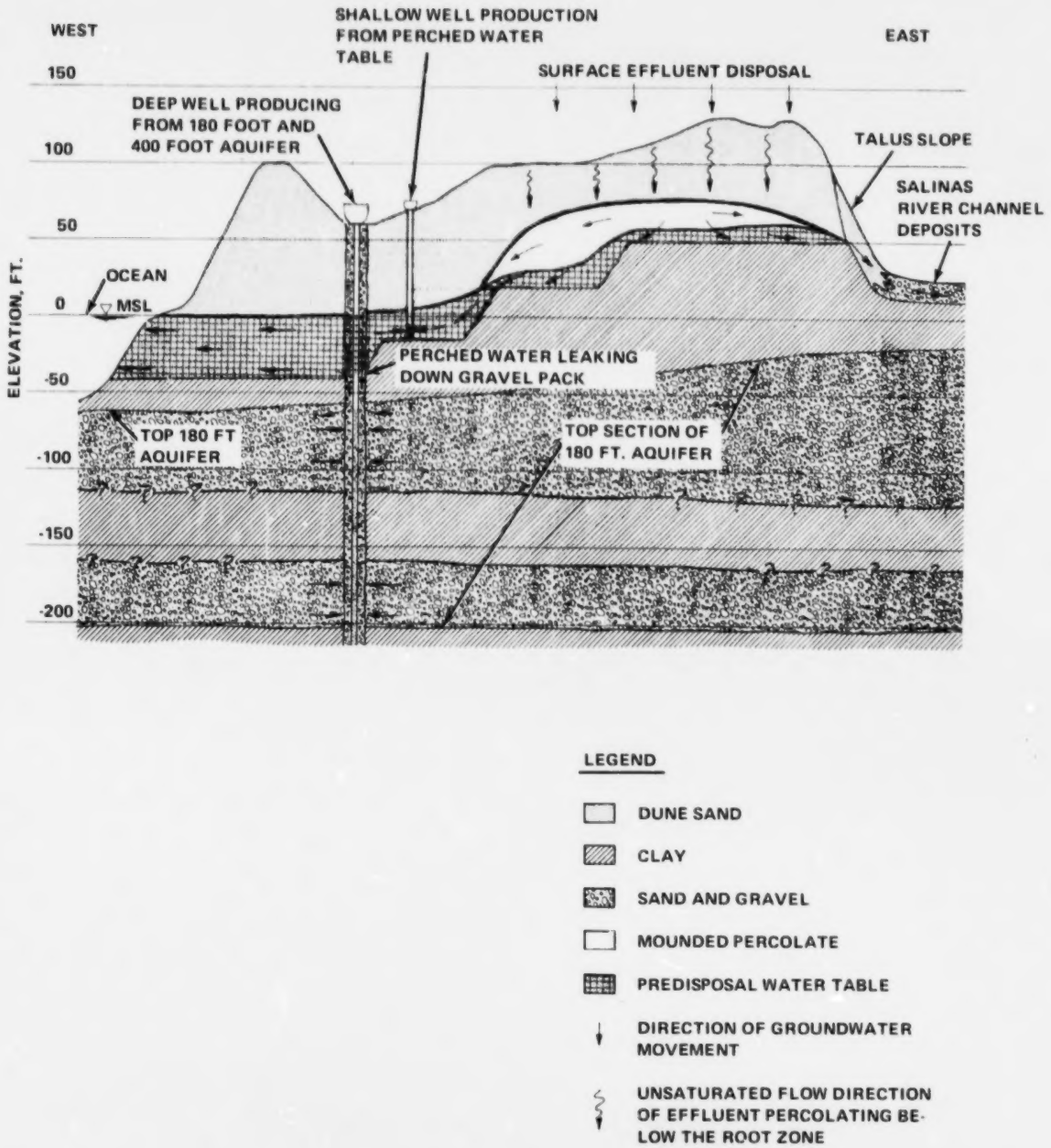

Figure IV-4. Typical groundwater mound.[12]

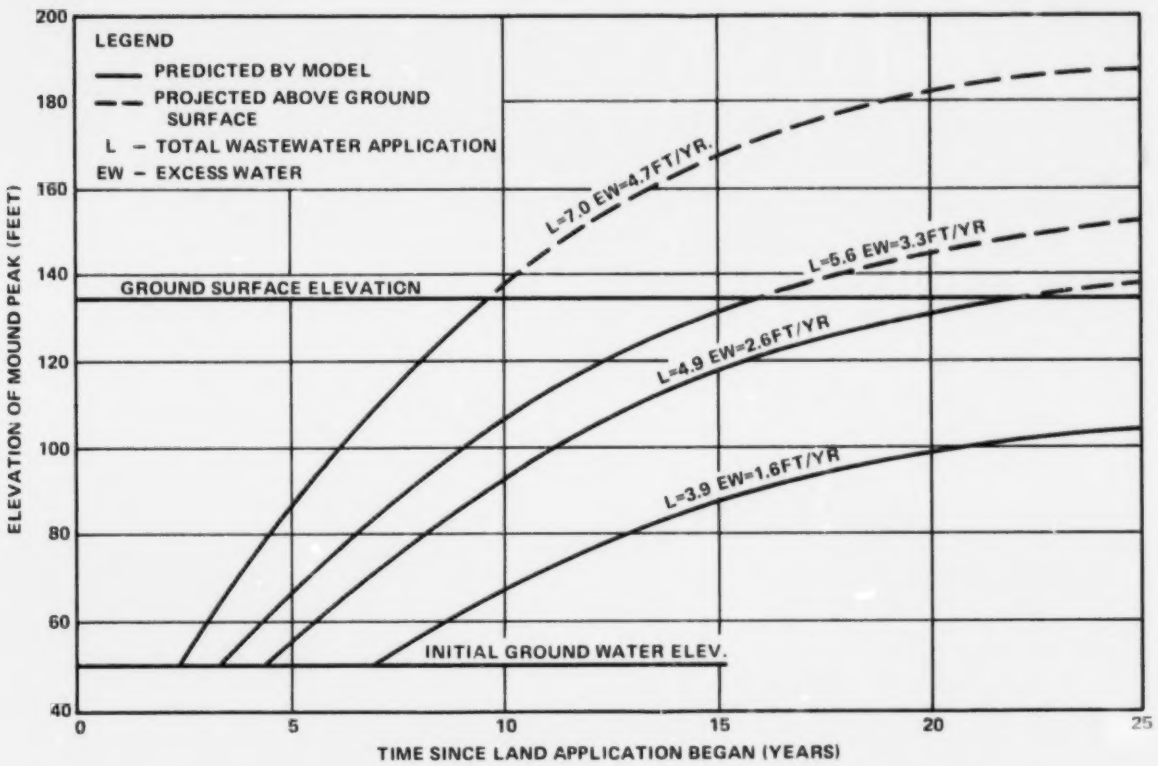

Figure IV-5. Relationship between height of groundwater mound and time under various loading rates at application site on figure IV-4.[12]

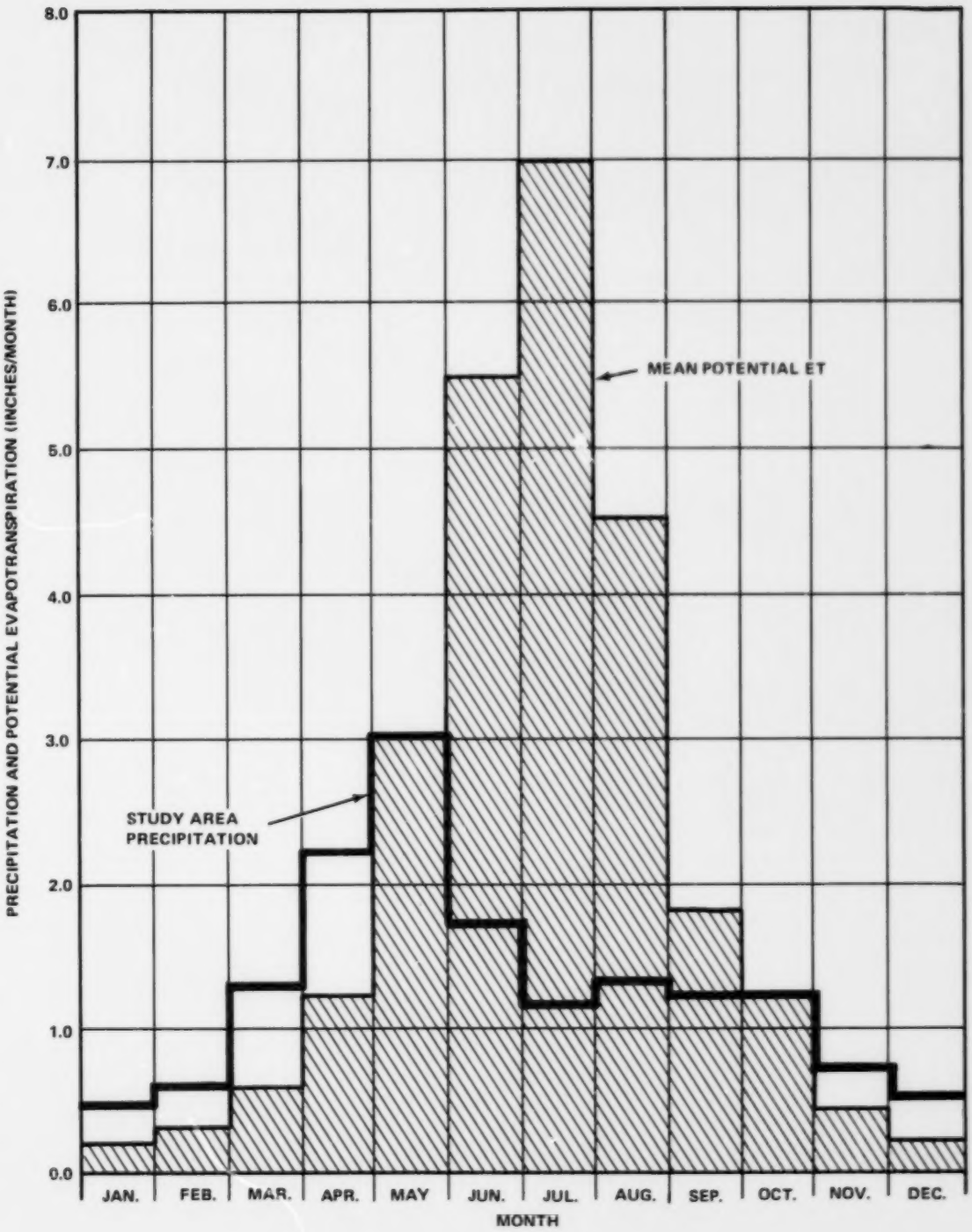

Figure IV-6. Precipitation and potential evapotranspiration (ET) for sample study area on figure IV-2.[1]

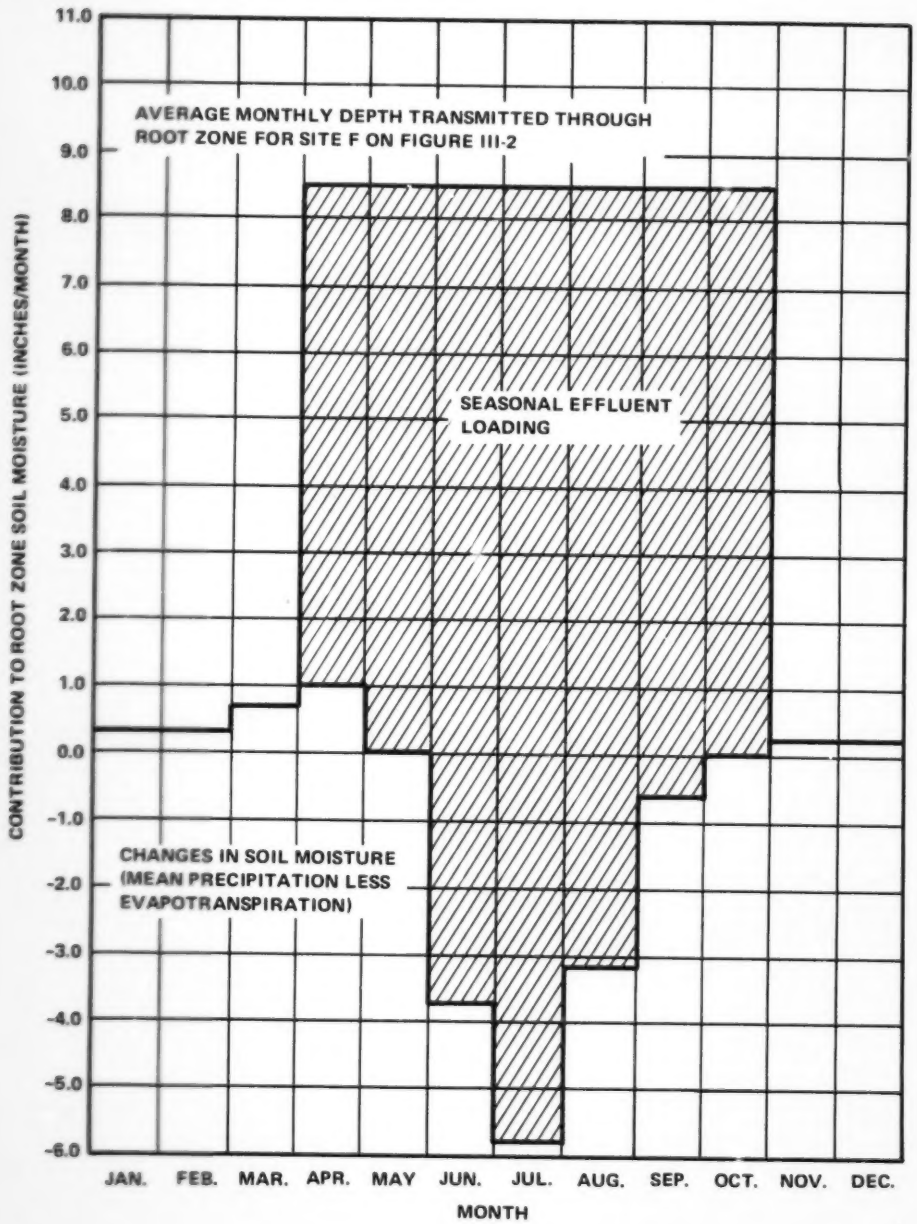

Figure IV-7. Changes in soil moisture and effluent application.[1]

investigation, and possibly even a pilot study, may be required to determine the sustained loading constraint over a long time period.

NITROGEN REMOVAL

Recent technical papers indicate many complex processes are involved in the removal of the various nitrogen forms in a soil-plant system.[13,14,15] For a short period of time, ammonia and organic forms of nitrogen are retained in the soil by adsorption and ion exchange until mineralized to the nitrate form. All nitrogen, regardless of form when applied, is eventually mineralized to the nitrate form unless lost by volatilization.[15] Nitrogen in the nitrate form is very mobile and subject to movement with the water. Thus, nitrogen loading and leaching below the root zone must be considered in the design to prevent excess nitrogen movement to the groundwater.

Nitrogen removal from applied wastewater occurs through crop uptake, growth of microbial cells, volatilization of ammonia, conversion to nonbiodegradable organic matter, and denitrification. A conceptual drawing of the nitrogen removal processes is shown in figure IV-8. The first few years after a land application system is initiated, the microbial population may increase dramatically and result in increased nitrogen storage in the soil profile. Nonbiodegradable organic matter containing nitrogen accumulates in a similar manner until a new steady state condition is reached. The decay rate of the accumulated organic nitrogen equals its production when a steady state condition is reached.

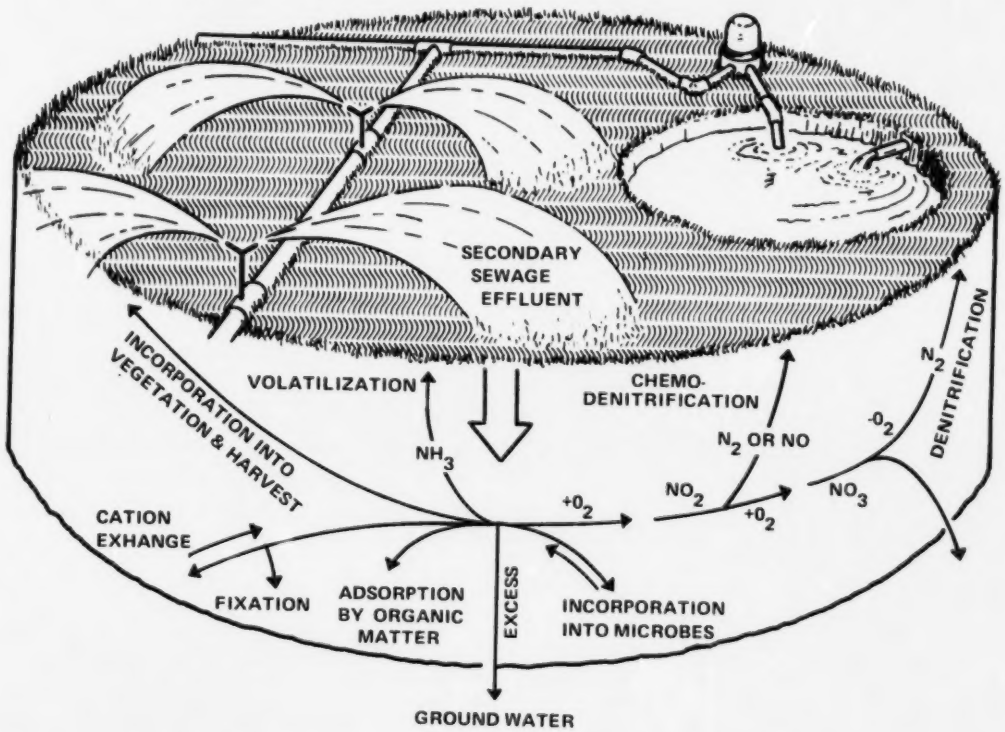

Figure IV-8. Schematic drawing of nitrogen transformations.[12]

The length of time needed to reach the steady state condition and the change of nitrogen storage in the profile is not well understood. Data from the Melbourne and Metropolitan Board of Works sewage farm at Werribee indicate that the storage process may still be continuing at a relatively constant rate after several decades on pastures.[16,17] However, a more typical situation for cultivated agricultural soils is an increase to a new steady state level in 5 to 10 years. Thus, the accumulation of nitrogen in the soil profile may not be important for a typical land application project life (20 years or more). Once a steady state condition is reached, there will be no further nitrogen removal by the soil through growth of aerobic microbes and conversion to nonbiodegradable organic matter.

Volatilization of ammonia is only important in soils of high pH (alkaline) and where ammonia does not come in contact with the soil or exceeds the adsorption capacity of the profile. Many soils have a high capacity for ammonia adsorption, so what volatilization does occur takes place before adsorption. Under most conditions, volatilization of ammonia will not be a major removal mechanism.

Crop uptake and denitrification are considered the only two reliable long-term mechanisms (steady state conditions) for removal of nitrogen.[15,18] As with normal agricultural activities, crop removal of nitrogen is dominant in irrigation and high-rate irrigation processes with denitrification being much less important. Denitrification is dominant and crop uptake negligible in the infiltration-percolation process under proper wet-dry cycles. Both crop uptake and denitrification appear to be significant nitrogen removal mechanisms for the overland flow process method.

Nitrogen removal by crops is dependent on the length of growing season and crop type as well as nitrogen availability. Crop requirements for nitrogen during the growing season approximately parallel the evapotranspiration demand. Thus, applications paralleling the seasonal changes in evapotranspiration as shown in figure IV-6 may be more beneficial to the crop than a constant application.

Crops normally used with land application can be divided into three broad groups and removal rates. A forage crop will remove 150 to 600 lb/acre or more, field crops will remove 75 to 150 lb/acre, and forests will remove 20 to 100 lb/acre, as shown in table IV-2. Wide variation occurs within each group, and some crops do not fit this generalization.

Some crops show luxurious uptake of nutrients with total removal being as much as twice the noted values. Nitrogen removal is generally dependent on the amount applied. However, removal efficiency (nitrogen removed by crop divided by nitrogen applied times 100) decreases as the loading increases. A removal efficiency of 84 and 68 percent, respectively, was reported for reed canary grass with 421 and 524 lb/acre of total nitrogen applied.[18] Figures IV-9 and IV-10 show nitrogen removal and removal efficiency for corn grain and corn silage. Removal efficiency may be greater than 100 percent when loadings are low becauses of the release of nitrogen stored in the soil.

Data from Kardos et al.[19] also indicate that as nitrogen removal efficiency decreases, nitrate-nitrogen concentrations in the percolate may increase significantly, as shown in figure IV-11 for a corn crop. However, the increase in concentration will depend on the crop grown. For example, the nitrate-nitrogen concentration in percolate at a 4-foot depth beneath reed canary grass[19] averaged 3.1 mg/l for 4 years and showed no trend of increasing as the total nitrogen applied increased. Crops vary widely in efficiency for nitrogen removal and total amount removed depending on both the crop species and nitrogen loading. Where strict limits are placed on the nitrogen concentration of percolate from land application, a crop with high removal efficiency together with controlled loadings may be required.

Table IV-2.—*Reported nutrient removal by forage crops, field crops, and forest crops*

	Nitrogen uptake (lb/ac/yr)
Forage crops	
Costal bermuda grass	480-600
Reed canary grass	226-359
Fescue	275
Alfalfa	155-220[a]
Sweet clover	158[a]
Red clover	77-126[a]
Lespedeza hay	130
Field crops	
Corn	155
Soy beans	94-113[a]
Irish potatoes	108
Cotton	66-100
Milo maize	81
Wheat	50-76
Sweet potatoes	75
Sugar beets	73
Barley	63
Oats	53
Forest crops	
Young deciduous (up to 5 years)	100[b]
Young evergreen (up to 5 years)	60[b]
Medium and mature deciduous	30-50[b]
Medium and mature evergreen	20-30[b]

[a]Legumes remove substantial nitrogen requirements from the air.
[b]Estimated.
Source: EPA (1975) Table 6; Driver et al. (1972); and National Plant Food Institute.

Data from the University of California[20] showed decreases in the efficiency of removing applied fertilizer similar to those shown in figures IV-9 and IV-10. The data were obtained from the application of fertilizer and irrigation water. The nitrate-nitrogen concentrations in the unsaturated soil water below the root zone of agricultural sites were 6 to 491 (average 56) and 9 to 1,151 (average 86) mg/l for coastal and inland counties, respectively. Nitrate-nitrogen concentrations in groundwater beneath agricultural sites were substantially lower, 1 to 244 (average 32) and 4 to 40 (average 16) mg/l for the coastal and inland counties, respectively. These data from agricultural sites indicate that it is difficult to control nitrogen movement below agricultural crops.

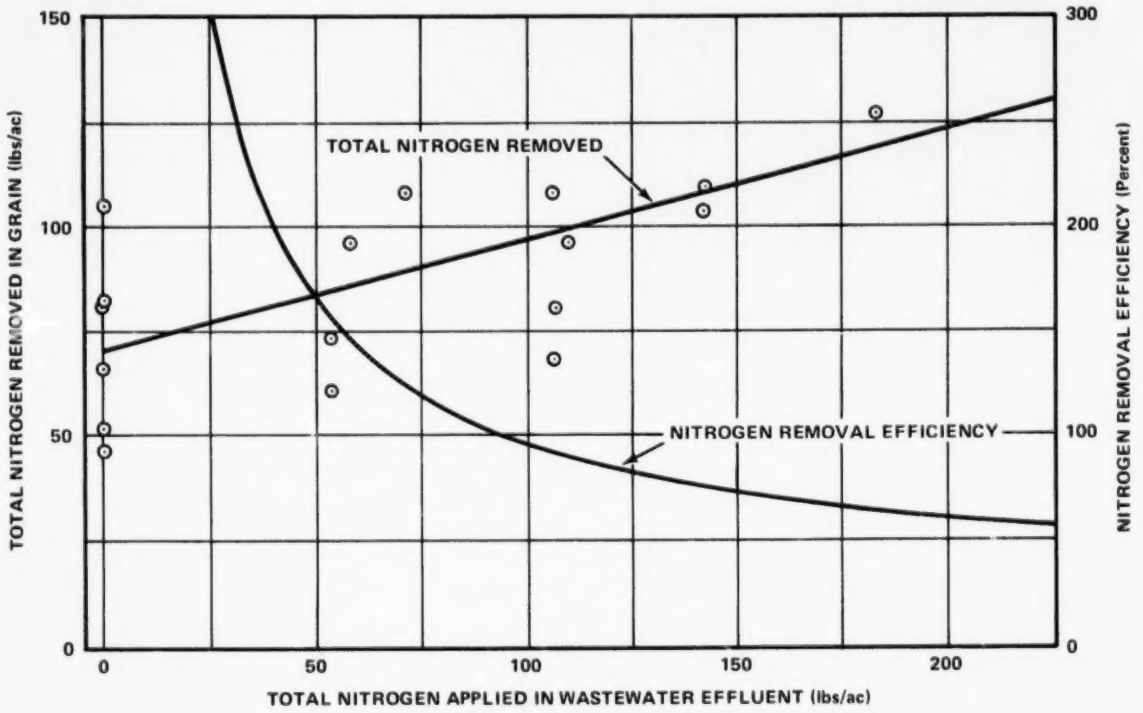

Figure IV-9. Total nitrogen removed and removal efficiency for grain corn.[19]

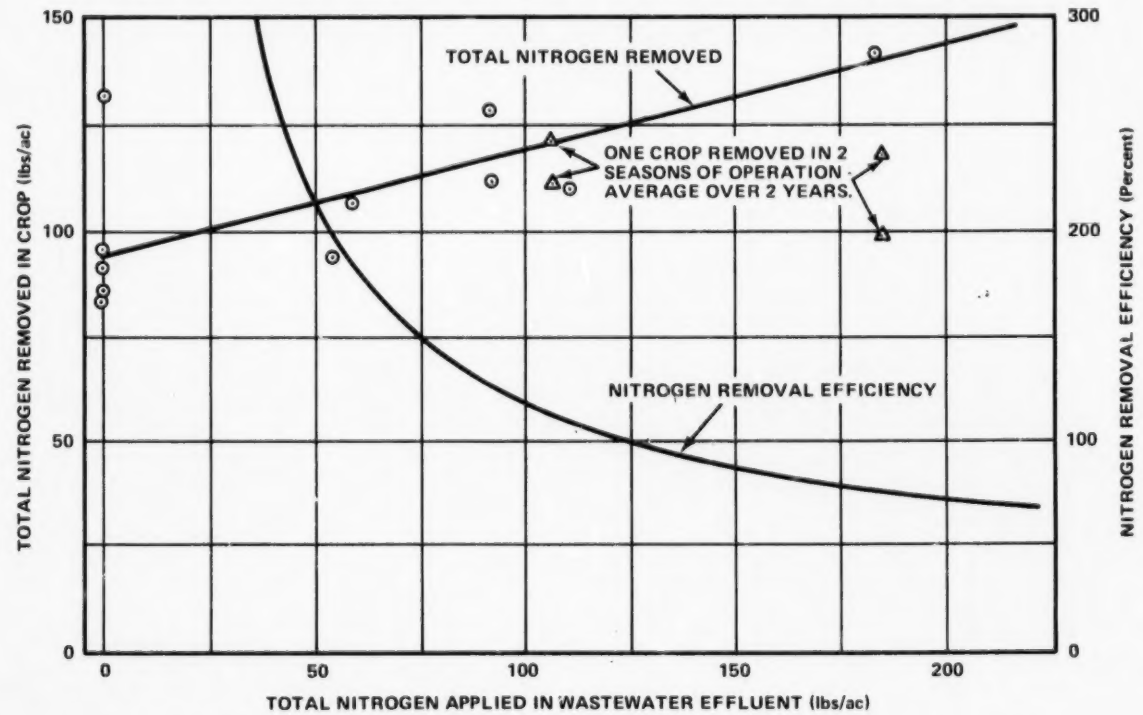

Figure IV-10. Total nitrogen removed and removal efficiency for corn silage.[19]

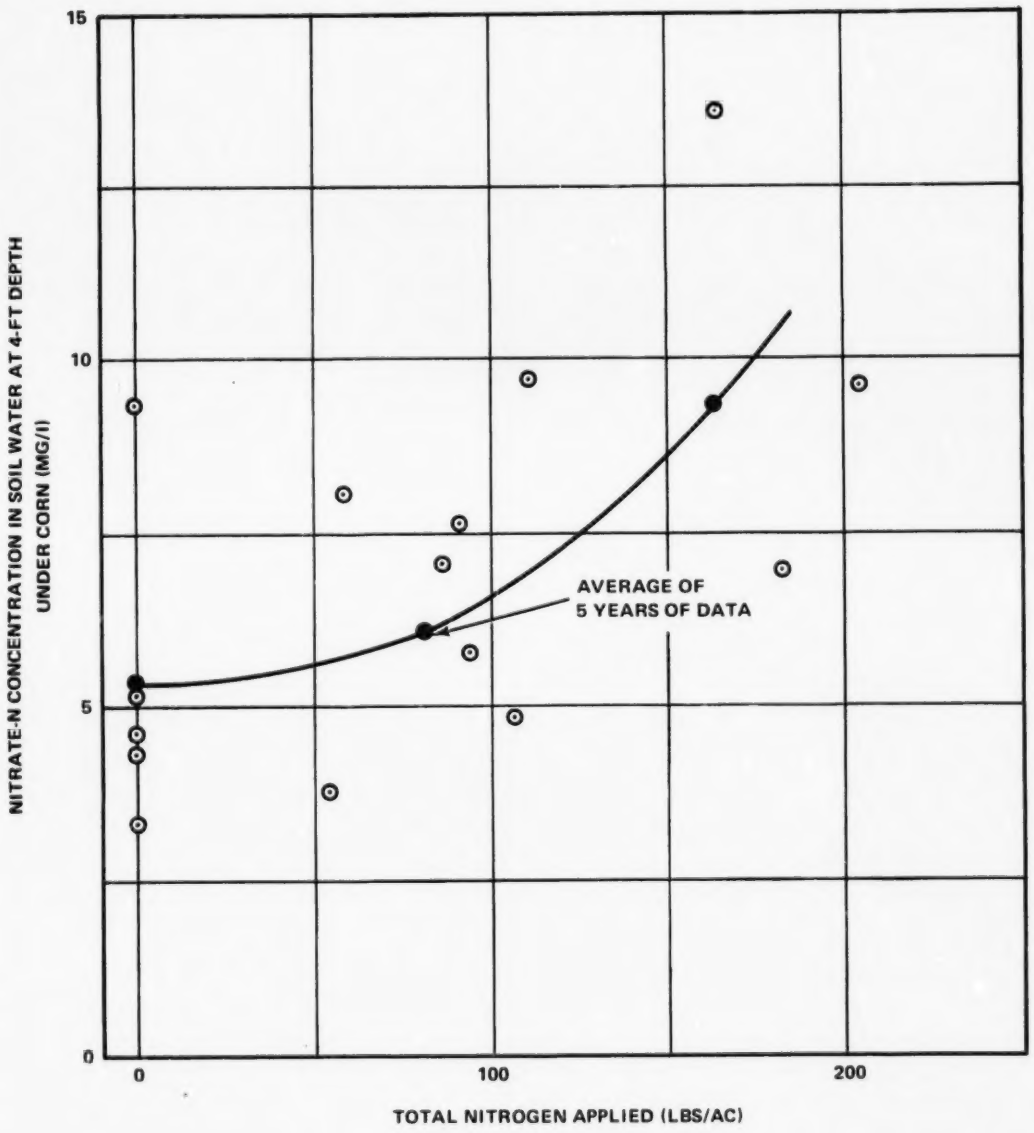

Figure IV-11. Nitrate-nitrogen concentration of percolate beneath a corn crop versus total nitrogen applied in wastewater.[19]

The University of California[20] has reported progress in using computer modeling to predict nitrogen concentrations and transport in cropped, irrigated lands. The main objective is to predict nitrogen leaching losses from the root zone as a function of fertilizer application rates and irrigation management. As a subproject, the application of sewage effluent on land was modeled, and a paper covering the model was presented at the First Annual NSF Trace Contaminants Conference at Oak Ridge National Laboratory in August 1973.

Denitrification, the conversion of nitrate-nitrogen to nitrogen gas by bacteria with a carbon source and in the absence of oxygen, occurs naturally in all soil systems. The denitrification rate is highest for stratified soils with saturated or near saturated conditions. The lowest denitrification rates occur in uniform soils with moderate to rapid permeabilities. Because the root zone must be aerated for most agricultural crops, significant anaerobic areas will not persist and high rates of denitrification are not likely to occur within the active root zone. Anaerobic conditions can develop toward the bottom of the root zone, and nitrates moving below an active root zone would then be subject to denitrification. However, carbon decreases with depth, and essentially no denitrification occurs below a 10-foot depth for most soils.[13]

Denitrification has been shown to vary from 10 percent to more than 80 percent of the nitrate-nitrogen moving below the root zone. Actual rates will be dependent on oxygen diffusion rates and supply of a carbon source. Denitrification will be difficult to design for and control under field conditions for irrigation and high-rate irrigation. An elaborate system to create anaerobic conditions and to supply a carbon source for the denitrifying bacteria is required to accomplish predictable high rates of denitrification in soil systems. Also, anaerobic soil conditions tend to lower the soil pH and increase solubility of some pollutants which may then leach to the groundwater.

High levels of nitrogen can interfere with productivity in some crops. Sugar beets, for example, will not obtain high sugar levels if excess nitrogen is available late in the season. Grape flavor, as well as the sugar content and pH, factors controlling wine quality, is dependent in part on nitrogen availability.

There is little hazard of nitrogen toxicity of crops where typical municipal effluent is applied to land. When loadings are low, the total quantities applied are usually comparable to normal fertilizer applications. When loadings are high, the nitrogen is leached through the soil profile and thus should be little problem to the plant.

A potential toxicity problem occurs when applications continue through the winter when nitrogen is not nitrified. The organic nitrogen and ammonia-nitrogen are stored in the soil during winter. When the weather warms, nitrification occurs over a short time and concentrations may reach high levels. With excess nitrogen available, some crops, particularly forages, can accumulate high levels of nitrate which may be toxic to livestock and people. The potential nitrate toxicity from crops would normally occur only during early spring, probably before the first harvest. The potential hazard should not persist because leaching through the soil should reduce soil nitrate levels. However, pollution of the groundwater may then be a problem. Monitoring of vegetation can detect potential toxicity problems before they cause damage.

NITROGEN BALANCE

Under long-term operation (steady state conditions), the removal of nitrogen by the crop and denitrification will control the nitrogen concentration in the percolate. Initially, higher rates of removal may be obtained with an associated accumulation of organic nitrogen (humus) in the soil, as discussed earlier. After a few years, the rate of accumulation will decline and will reach a steady state condition with little or no additional accumulation.

Typical steady state nitrogen balance estimates for two effluent application rates and two crop groups are shown in table IV-3 to illustrate a sample nitrogen budget. With steady state conditions, the wastewater nitrogen additions of 1,300, 300, and 135 lb/acre produce 10, 5, and 5 mg/l nitrogen concentrations in the percolate water as indicated. The balances in table IV-3 are based on an assumed removal by crops and denitrification. Increasing the loadings above those shown will probably increase the nitrogen concentration and the pounds of nitrogen in the percolate unless the crop is changed. Requirements for a lower nitrogen concentration in the percolate will necessitate reductions in the loading rate. Thus, nitrogen limitations for discharge may control the loading rate.

Except for legume plants, nitrogen additions to the root zone from rainfall and fixation (atmospheric nitrogen made available by bacteria living in the soil) are approximately equal to the incidental losses from volatilization of ammonia and other removal mechanisms. Bacteria living on the roots of legume plants fix (convert to an available form) large quantities of nitrogen from the atmosphere. Indications are that with effluent application, where high nitrogen loads are available, this fixation process is greatly reduced.

A soil scientist or agronomist can be helpful in determining estimated losses from volatilization and denitrification. Such estimates may be used during preliminary planning. Verification of the assumed losses will be necessary prior to final design if nitrogen removal is a critical parameter (i.e., controls loading rate). Verification can be made by pilot studies with measurement of losses. Unfortunately pilot projects typically take several years to become steady state for nitrogen removal. It is especially important to determine nitrogen stored in the soil during the pilot study and to subtract the storage from the budget to obtain a valid steady state condition.

PHOSPHORUS

Phosphorus is removed by crops, precipitation, and adsorption by soil colloids. The removal of phosphorus is, therefore, dependent on the soil texture, cation exchange capacity, soil pH, presence of calcium, amount of iron and aluminum oxides present, and uptake of phosphorus by the crop. Because of these removal mechanisms, there is a large capacity for phosphorus removal, and little movement of phosphorus through the soil profile with the drainage water can be expected. Phosphorus removal capacity is finite, and over a long time period or with high loadings, the phosphorus additions may exceed the soil's capacity for removal.

Phosphorus removal by adsorption can be estimated by the Langmuir adsorption isotherm[21] as follows:

$$\frac{M}{x/m} = \frac{1}{kb} + \frac{M}{b'}$$

Table IV-3.—*Approximate nitrogen balance for two land application processes under steady state conditions (lb/ac except as noted)*[7]

	Infiltration-percolation	High-rate irrigation
Forage crop		
Application		
Effluent (ac ft/ac)	24	6.9
Nitrogen in effluent	1,300	300
Nitrogen added in precipitation and fixation less losses to ammonia volatilization, etc.	0	0
Removed by crop	300	200
Leached below root zone	1,000	100
Lost to denitrification (35 and 25 percent)	350	25
Returned to groundwater		
Treated effluent (ac ft/ac)	24	5.6
Nitrogen in treated effluent	650	75
Concentration in return flows (mg/l)	10	5
Cultivated field crop		
Application		
Effluent (ac ft/ac)		3.1
Nitrogen in effluent		135
Nitrogen added in precipitation and fixation less losses to ammonia volatilization, etc.		0
Removed by crop		100
Leached below root zone		35
Lost to denitrification (25 percent)		9
Returned to groundwater		
Treated effluent (ac ft/ac)		1.8
Nitrogen in treated effluent		26
Concentration in return flows (mg/l)		5

where M = the activity of the ion in moles per liter, x/m = meq of ion M adsorbed per 100 grams of adsorber, k = constant related to bonding energy, and b = the maximum amount of ion M in meq/100 g that will be adsorbed by a given adsorber. The adsorption capacity has been estimated for several soils with a range of 77 to over 900 lb/acre-foot of soil profile.[21] At common loading rates of wastewater effluents, a soil with a storage capacity of only 77 lb/acre-foot would be saturated in a few years.

Ellis indicates that the adsorption capacity of the soil can be restored in a few months. Apparently this saturation and restoration cycle can occur many times. Restoration occurs when adsorbed phosphorus is precipitated or removed by crops. At a pH below 6, phosphate is thought to precipitate with iron and aluminum.[15] Thus, iron and aluminum contents of soil will determine long-term storage of phosphorus for acid soils. For neutral or basic soils, the primary precipitate is with calcium. Apparently precipitation occurs rapidly above a pH of 6.5 and where the ratio of calcium to phosphate concentration is at least 50:1 for the soil water solution.

For many soils, the total removal capacity is large and would greatly exceed the planning life of the land application project. For coarse textured soils with little calcium, iron, or aluminum, the removal capacity may be limited. If phosphorus removal is critical for these conditions, a soil chemist should be consulted regarding the storage capacity for phosphorus. Phosphorus concentrations of the soil water at the 4-foot depth beneath crops generally average less than 0.1 mg/l with an upper limit of about 1.5 mg/l.[19] A more detailed discussion of phosphorus adsorption isotherms and methods for estimating the concentration in percolate is given by Taylor and Kunishi.[22]

Phosphorus accumulating in soil over a long period of time may potentially interfere with crop growth. This interference generally would occur as a nutrient imbalance in the plant, that is, high phosphorus levels in the soil may reduce the availability of some crop micronutrients. Thus, the plant may develop low levels of other required nutrients rather than toxic levels of phosphorus. Precipitation of the phosphorus would be expected to minimize any toxicity problem; otherwise, corrective measures may be taken.

SUSPENDED SOLIDS

Suspended solids in typical secondary treated effluents are low enough that there normally is no problem encountered with any of the land application processes. Food processing wastes, having much higher concentrations, have been applied on land without serious problems.

In all but coarse sands and gravel, the suspended solids are filtered out at or very close to the soil surface. With high concentrations of some solids, the soil surface may be coated to the extent that infiltration rates are reduced. If mineral solids are applied, periodic tilling of the soil may be necessary. With coarse textured soils and high solid loading, it may be necessary to apply a surface layer of a finer material or reduce solids loads in order to prevent clogging pore spaces deeper in the soil. Solids more typically are organic, and a rest period which allows the organic material to dry and oxidize may be sufficient to restore infiltration rates.

High inorganic suspended solids loading rates could result in a long-term accumulation of solids that would interfere with the application system's operation. Inorganic solids are not

subject to the decay process which removes organic solids. If high inorganic suspended solids are present, pilot studies of infiltration using the effluent may be desirable during planning and design to evaluate the impacts.

BOD AND COD OXIDATION

BOD is often associated with the suspended solids, while COD is more often associated with dissolved organic solids. Because the suspended material is filtered out near the surface, the BOD load will normally not extend more than a few inches into the soil. At these shallow depths, oxygen diffusion rates are high, and there should be ample opportunity for reduction of BOD before percolation reaches the groundwater.

The soluble COD-causing material will be carried into the soil with the water. Organic cations and basic compounds are removed by cation exchange. Polar molecules and some large molecules are adsorbed. Organic anions are precipitated with iron and calcium. Large organic cations are held tightly, while polar molecules are not. Some organics form films on soil materials. Low soil moisture is a strong contributing factor to removal of many organic compounds. Thus, COD removal is enhanced by low loadings and long rest periods. If the COD-causing material is adsorbed, oxidation will be necessary to restore the soil's adsorption capacity. All organics are subject to decomposition in soil, but a long time may be required.[15]

Because of these factors, the removal capacity for COD-causing materials is expected to be limited for high loading rates. Low COD levels found in domestic wastewater should pose no problems in the soil. Removal and oxidation are dependent on many factors and are hard to estimate. High levels of stable COD materials that have a long decay half-life may require reduced loadings to permit oxidation if the COD must be removed.

The total oxygen demand of domestic wastewater applied to land is usually low in comparison to the oxygen requirement for an actively growing crop as shown in table IV-4. The additional oxygen requirement imposed by the wastewater application is not likely of itself to significantly affect the soil or crop. Oxygen demand loadings by wastewater of 50 to 100 lb/acre/day have been used successfully. The upper limit is dependent on the soil, system management, and temperature.

INORGANIC CHEMICALS

Table IV-5 shows recommended concentration limits for specific elements for irrigation water based on an application of 3 ft/year, a typical application rate of the irrigation process. Estimated limits are also shown for loadings of 8 and 80 ft/year as might be used with high-rate irrigation or infiltration-percolation. If these criteria are met, there should be little concern about toxic effects on plants or excessive accumulation in soils. Many of the elements are micronutrients or trace elements required by plants in small quantities.

Many of the specific elements shown in table IV-5 are also heavy metals and have received a great deal of attention because of their impact on the environment. Most of the heavy metals are effectively removed as water percolates through the soil. The mechanisms for

Table IV-4.—*Typical oxygen demands and loading rates for soil*[10]

	Oxygen consumption	
	lb/ac/hr	average lb/ac/day
Fallow soil with no fresh organics	1-2	36
Fallow soil following addition of organic residues	2-4	72
Soil with growing plants	3-6	108
Typical limits of BOD loading on land for municipal wastewater[a]		100+

[a]Reduction for low temperature may be necessary.

removal are adsorption on the exchange complex or with iron, aluminum, and other elements, and precipitation in very insoluble forms. In general, the trace elements are most insoluble at soil pH near 7.0.[15] Thus, controlling the pH near neutral, 7.0, by addition of soil amendments such as lime, is one method of maximizing the soil capacity for removing and storing heavy metals.

Some precipitants such as iron and manganese become more soluble under anaerobic conditions and are then subject to leaching and potential pollution of the groundwater. Maintaining an aerobic soil may be important to effective removal of some heavy metals. In soluble forms, the heavy metals are available to plants and subject to movement to the groundwater. Management to maintain low solubility is a key to heavy metal removal. If good management is practiced, water transmitted through the soil profile in the irrigation or high-rate irrigation processes should be suitable for most uses. However, under some conditions and for some uses, total salt concentrations may be higher than desirable because of salt concentration by evapotranspiration.

For the overland flow process, water does not move through the soil, so there is little chance for heavy metal removal in the soil matrix. For the irrigation and high-rate irrigation processes, the soil will be very similar and heavy metal removal will be similar. Because of the higher loadings for infiltration-percolation, the soil capacity for heavy metal removal will be reached sooner. The limitation for heavy metals concentration should be a function of site life and loading rate. The higher the loading rate and the longer the site life desired, the lower the concentration limitation should be as shown in table IV-5. Estimated concentration limitations for infiltration-percolation (80 feet per year application) are lower than for high-rate irrigation (8 feet per year application). Removal of heavy metals by the soil profile probably will decrease as the loading rate increases.

Trace elements, salt, or other pollutants toxic to plants may show toxic effects sooner when high concentrations directly contact the vegetation than when the same concentrations are applied to the soil. Plants may absorb some pollutants directly through contacted exposed parts. Sprinkler and flood irrigation produce direct water contact on the plant. If high concentrations of pollutants are of concern, furrow irrigation might be used to prevent foliage contact.

Table IV-5.—*Recommended and estimated maximum concentrations of specific ions in irrigation waters*[a] *(mg/l)*

Element	Removal mechanism[b]	For waters used continuously on all soil	For waters used up to 20 years on fine textured soils of pH 6.0 to 8.5		
		3 ft/yr application recommended limit[c]	3 ft/yr application recommended limit[c]	8 ft/yr application estimated limit	80 ft/yr application estimated limit
Aluminum	PR, S	5.0	20.0	8.0	0.8
Arsenic	AD, S	0.10	2.0	8.0	0.08
Beryllium	PR	0.10	0.50	0.2	0.02
Boron	AD, W	0.75	2.0-10.0	2.0	2.0
Cadmium	AD, CE, S	0.010	0.050	0.02	0.002
Chromium	AD, CE, S	0.10	1.0	0.4	0.04
Cobalt	AD, CE, S	0.050	5.0	2.0	0.2
Copper	AD, CE, S	0.20	5.0	2.0	0.2
Fluoride	AD, S	1.0	15.0	6.0	0.6
Iron	PR, CE, S	5.0	20.0	8.0	0.8
Lead	AD, CE, S	5.0	10.0	4.0	0.4
Lithium	CE, W	2.5[d]	2.5[d]	2.5	2.5
Manganese	PR, CE, S	0.20	10.0	4.0	0.4
Mercury	AD, CE, S	—	—	—	—
Molybdenum	AD, S	0.010	0.050[e]	0.02[e]	0.002[e]
Nickel	AD, CE, S	0.20	2.0	0.8	0.08
Selenium	AE, W	0.020	0.020	0.02	0.02
Silver	AD, CE, S	—	—	—	—
Zinc	AD, CE, S	2.0	10.0	4.0	0.4

[a]These levels will normally not adversely affect plants or soils. No data are available for mercury, silver, tin, titanium, or tungsten.

[b]AD = adsorption with iron or aluminum hydroxide, pH dependent; AE = anion exchange; CE = cation exchange; PR = precipitate, pH dependent—iron and manganese are also subject to changes by oxidation reduction reaction; S = strong strength of removal; W = weak strength of removal.

[c]EPA Water Quality Criteria, 1972.

[d]Recommended maximum concentration for irrigating citrus is 0.075 mg/l.

[e]For only acid fine textured soils or acid soils with relatively high iron oxide contents.

SALTS

Salts are found in all natural waters from the weathering of soil and rocks into the basic elements. Because irrigation water lost to evaporation and transpiration leaves salts behind, water consumption increased above present levels by evapotranspiration will increase TDS concentrations in the soil. The concentrating effect of evapotranspiration is directly proportional to the water lost to evaporation and evapotranspiration. The concentrating effect occurs with all irrigation systems, and additional water is applied as needed to leach the salts. Conversely, the increase in weathering is less known and may be more important to land application in water short areas.

Recent research, primarily at the Soil Salinity Laboratory at Riverside, California[23,24,25] shows that the weathering rates of soil into salt are dependent on temperature, water quality, and the quantity of water percolating through the soil. As more water of the same quality is applied, higher weathering rates result. With little percolate water, less salt may be leached out of the profile than applied, indicating salt precipitation in the profile. With large volumes of percolate water, more salt may be leached out of the profile than applied, indicating desolution of salts or weathering of the soil profile. A model has been developed and verified which describes the above processes.

Apparently the acidifying reaction producing two hydrogen ions as each ammonium ion is oxidized to nitrate as described by Broadbent[13] is an important factor in the increased leaching. The relative magnitude of the nitrification and denitrification processes will be a key factor in the acidification reaction.

The effect of leaching by land application loading of 2.3, 6.0, and 29.0 feet per year for the example study area is indicated in table IV-6. Table IV-6 shows that salt concentrations would increase substantially for all three alternative loadings. More important than the concentrations are the salt loading and the impact on the receiving stream.

A loading rate of 2.3 feet, which is consistent with normal irrigation practice, has little impact on the total salt load of the stream. A loading rate of 6.0 feet, which might be used for high-rate irrigation, has a rather significant impact with an increase of 19.8 percent on the total salt load for the small stream system. This salt load is a result of desolution of calcium carbonate from the highly calcareous soil profile. This desolution can continue indefinitely. A loading of 29.0 feet as might be used for infiltration-percolation has the greatest impact on the receiving stream with a 30.2 percent increase in the total salt load. Salt loads for this alternative are from desolution of calcium carbonate and weathering of soil and gravel material into basic elements. For the highest loading rate, the reported values represent a maximum; actual values may be lower. Additional basic research must be conducted to determine the validity of the salt loadings problem illustrated above.

In the water short west where consumptive use of water through irrigation produces high salt concentrations, the impacts of an increased salt load as a result of increased leaching may be significant. The impact on stream quality in the areas of excess water and little irrigation will be minimal.

The effects of salts on soils and plants are dependent on chemical characteristics of the wastewater and the physical and chemical properties of the soil. The higher levels of salts,

Table IV-6.—*Salt concentrations and salt loadings for three land application rates*[a,1]

	Loading		
	2.3 ft	6.0 ft	29.0 ft
TDS concentration (mg/l)			
In applied water	370	370	370
Expected in percolate	2,000	860	770
Total salts			
Applied (T/acre)	1.13	3.01	15.08
Drained (T/acre)	1.20	4.91	28.45
Salt load (T/acre)	0.07	1.90	13.36
Total salts added (T/year)	1,000	8,500	13,000
Percent change in total salts in stream[b]	2.3	19.8	30.2

[a]Modeling contributed by USDA Soil Salinity Laboratory Staff, Riverside, California.
[b]Total average salt load at the stream mouth = 43,000 T/year.

total dissolved ionic solids (TDIS), in wastewater lead to some potential problems. Generally, the sodium adsorption ratio (SAR) given below and the TDIS are used to evaluate the quality of irrigation water:

$$SAR = \frac{NA+}{\sqrt{\frac{(Ca^{++} + Mg^{++})}{2}}}$$

Figure IV-12 shows the relationship between SAR and TDIS and the resultant hazard. The main effect of excess sodium is a dispersion of the clay content of soil and consequent reduction in permeability. Ellis[21] discussed one case of 25-percent reduction of infiltration rates resulting from 14 years of irrigation of agricultural crops by wastewater. Irrigation rates recommended for the crops were used. Even though the SAR was low, the effect was apparent. If loading rates higher than those required for irrigation had been used, the reduction in infiltration rates might have occurred much more quickly.

CLIMATE

Climate is a constraint on the timing of effluent application on land. For the irrigation and high-rate irrigation processes, effluent would not be applied during periods when the ground is frozen because runoff directly to the surface waters could occur. Also, maximum effluent loading will be limited to the active growing season. Plant and soil microorganism activity is greater during this time, so treatment of the effluent will be most effective then. Effluent applied durin dormant crop and soil periods may not receive the desired levels of

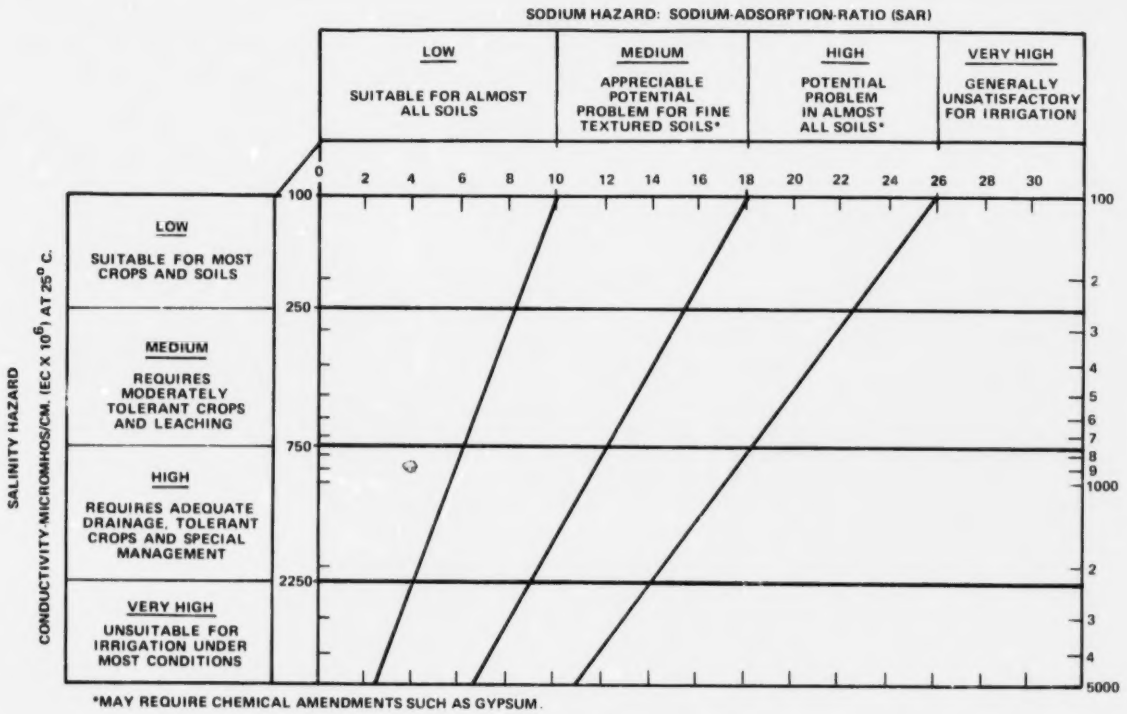

Figure IV-12. Sodium and salinity hazard.[26]

treatment. Growing season and frozen soil conditions should be considered carefully where high removal of pollutants is desired and where high reliability of treatment is a necessity.

For the infiltration-percolation process, the soil is much coarser to allow higher loadings. Because of the coarse soil required, applications of warm effluent may keep the soil from freezing under all but the most severe winter conditions. Surface irrigation is used successfully through the winter in Idaho and Minnesota where winter temperatures are extreme. Apparently the infiltration-percolation process can extend the application time appreciably; however, operating experience from Flushing Meadows indicates loadings probably should be reduced to about one-half of summer loadings to allow for slower drying and reduced rates of biological activity.

Chapter V

EFFLUENT LOADING DESIGN

FIELD INVESTIGATIONS

During the site selection process, some minimal field investigations by experienced soil scientists and hydrogeologists should be done to establish the accuracy of the available data, to evaluate differences between the sites, and to influence the site selection. Once the most suitable site(s) has been identified for each process, then the general loading established for site selection can be refined based on specific data for the selected site. If detailed information on soils and hydrogeology is available, trained scientists can evaluate and interpret the data to help establish a suitable loading based on the previously discussed constraints. If detailed data are not available, a reconnaissance investigation in the field should be made to collect the necessary data.

This chapter discusses the data and design factors that need to be considered to establish loading rates and alternative components for a facilities plan. For predesign and final design, much more detailed information is required. For example, loading and application rates must be based on detailed field investigations. Pilot studies may be required under some conditions. Normally soil scientists and hydrogeologists would make or would be heavily involved in these investigations.

CLIMATE AND HYDROLOGY

Preliminary information on such climatic factors as growing season, freezing temperatures, frozen soil, wind direction and velocity, precipitation, evaporation, and rainfall depth-duration-frequency data will be beneficial or required to establish loadings and operation. Since all of these factors are variable, a probability analysis may be helpful in establishing suitable criteria.

PROCESS LOADING

The design loading will be controlled by the most restrictive constraint, as discussed in the previous chapter. Once the climatic data are available, the evapotranspiration and irrigation requirements for different crops can be estimated.

For the irrigation process, the loading will be the irrigation requirement, which is evapotranspiration less effective precipitation plus the leaching requirement divided by the

irrigation efficiency. The irrigation requirement varies by month but generally follows the crop growth. Leaching requirements are high in low rainfall areas and are low in areas of higher precipitation.

If precipitation (P), evapotranspiration (ET), and design excess water (EW) for percolation are known, the maximum hydraulic loading rate (L) for high-rate irrigation or infiltration-percolation can be established from the following equation:

$$L = EW + ET - P.$$

As discussed earlier, the monthly loading should vary with season and precipitation so that the same amount of excess water percolates each month. Some evidence indicates that the excess water should be reduced as soil temperature decreases because of increased viscosity.[27] A drop in temperature from 77 degrees Fahrenheit (25 degrees Centigrade) to 32 degrees Fahrenheit (0 degrees Centigrade) doubles the viscosity and thus would reduce the excess water percolated by 50 percent.

Loadings of about 4 inches per week for overland flow[28] have been successful in a mild climate, using raw sewage with a settling of about 5 minutes before application. The effect of precipitation and other climatic factors on this loading is not known, and very little agricultural data are available on this process. Thus, at this time, design is more an art than a science for the overland flow process.

The storage requirement can be determined once the effluent application and flow rates are known. The monthly effluent loading may be calculated together with the monthly wastewater flows as a percent of the yearly total flow. Figure V-1 is an example of how to use these percentage figures to estimate the required storage volume. The total storage volume can easily be determined by adding up the percentages of wastewater flows which are not applied. Recurrence intervals for flows greater than average should be considered in sizing the storage facility.

Strict limitation on removal of pollutants such as nitrogen, phosphorus, heavy metals, or COD by the land application process as discussed earlier may place a greater constraint on loading than that obtained by the hydraulic limitation. For example, Powell and Culp[29] indicated nitrogen requirements resulted in lower loading limits than the hydraulic limitation. The paper prepared by Culp for this seminar discusses this example in greater detail.

If the mechanisms for removal of the pollutant in question are understood, it is possible to make estimates of the loading limitations to control concentrations. However, the removal mechanisms are complex and interrelated with other soil chemistry processes and management practices. Thus, complete understanding of these mechanisms is difficult to obtain. Methods for estimating loading limits where strict nitrogen, phosphorus, heavy metals, or COD constraints are imposed were discussed previously.

Field pilot work may be the only way of determining operational removals and management requirements to ensure the removal of pollutants within the set limits. Field pilot work is a long-term procedure. Thomas et al.[28] indicated that the overland flow process may not be stabilized after 18 months. Even longer times may be required to develop steady state conditions for other land application processes.

For poor soil conditions, hydraulic limitation will usually be the determining loading factor for high-rate irrigation and infiltration-percolation. For good soil conditions and strict limitations on pollutants, the nutrient requirement for the crop will limit applications for

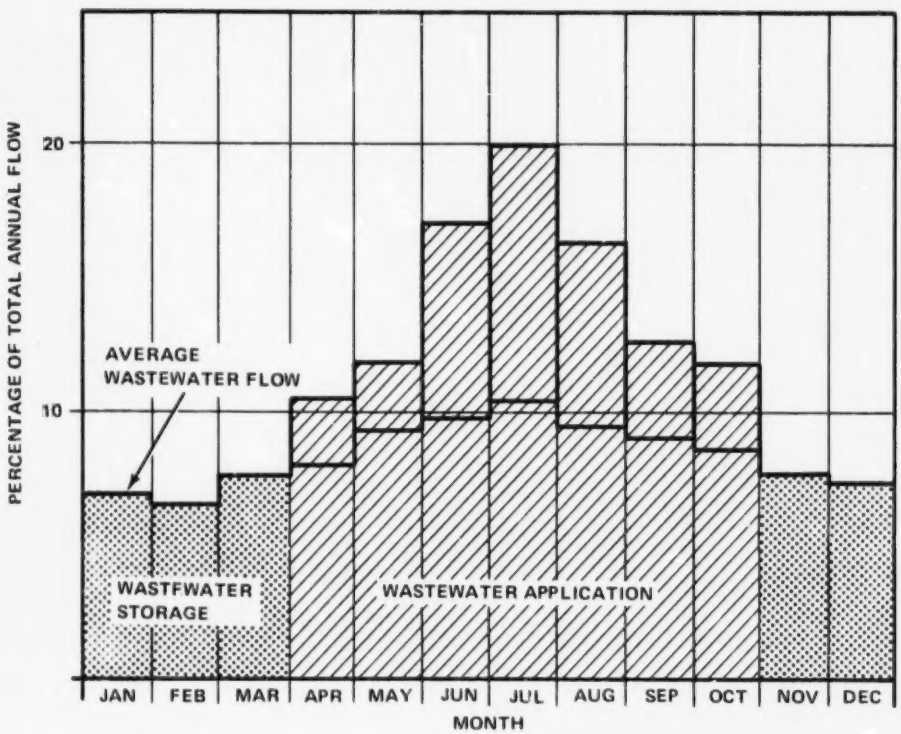

Figure V-1. Wastewater application versus wastewater flow and resulting storage requirements for data on figure IV-7.[1]

high-rate irrigation or infiltration-percolation. Loadings for the irrigation and overland flow processes are based on irrigation requirements and desired wastewater treatment, respectively.

REST PERIOD

The rest period is necessary to allow the soil to dry and re-aerate for restoration of the infiltration rate and the removal capacities. The length of the rest period depends on the soil properties, land application process, waste characteristics, climatic condition, crop, and time of year. It may range from a day or less to several weeks. Evapotranspiration and precipitation rates are very important in estimating the rest period. As a preliminary estimate, the removal between applications of 30 percent of the available water storage of the 4-foot profile should be adequate for the high-rate irrigation process. For infiltration-percolation, the rest period should be at least 50 percent of the total time for year-round operations with a minimum of several days between applications. For overland flow, the area is normally loaded on a daily basis for a few hours with 1 or 2 days of rest per week. For irrigation, the rest period is based on the evapotranspiration rate and the available water-holding capacity for the root zone. As a preliminary estimate, 50 percent of the available soil moisture is extracted between irrigations.

Chapter VI

COMPONENTS OF LAND APPLICATION SYSTEMS

An alternative land application system is identified once a specific application process, application site, irrigation method, and loading rate have been established. The next step is to determine the conceptual design of the system's components and operation. Alternative land application systems can only be evaluated once a conceptual layout of each system's components has been made and an operation plan identified. In this chapter, the purpose, function, and some suggested design criteria for system components are briefly discussed. The development of a plan for operation of the components of an alternative will also be mentioned. Chapter VII will outline a method for evaluating and comparing alternative systems.

SYSTEM COMPONENTS

Transport

A transport system is necessary to transport the wastewater from the point of collection to the application site. The delivery system must function year around and must be sized to carry peak flows. The delivery system is normally a pipeline but may be an open channel under some conditions.

Preapplication Treatment

Preapplication treatment ensures reliable operation of the land application process. Certain minimal levels of treatment may be specified by the state and usually depend on the crop to be grown. In the absence of state criteria, it may be necessary to establish criteria for the project using available data on requirements for reliable operation for the process and application method involved. The requirements for preapplication treatment for the various processes have been discussed in Design Factors – I.

Storage

During the nonapplication periods, the effluent may have to be stored. The required length of the storage period depends on the treatment process, site, and operation plan. Storage may range from a few days for a small system in mild climates to many months in cold climates. Storage is usually provided for all processes except overland flow.

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A storage facility may be a reservoir consisting of a dam and spillway or a lagoon with constructed berms surrounding it. The storage facility must be large enough to retain the pretreated wastewater plus precipitation and any surface runoff into the facility. If the storage facility is a reservoir, an effort should be made to minimize the area of the watershed that would drain into the reservoir. A spillway will normally be required, with design criteria established by the state. If state criteria do not exist, criteria of Federal agencies (Corps of Engineers, Soil Conservation Service, or Bureau of Reclamation) may be used. Total storage requirements are dependent on the wastewater flows, storage period, direct rainfall, and annual watershed yield. Frequencies of recurrence for wastewater flows, watershed yield, and stormwater runoff should be considered in determining the required storage capacity. A hydrologist should make the analyses of the watershed and storm runoff.

Distribution

The distribution system should be sized for peak flow of the application schedule at maximum operation time. Typically, irrigation systems operate 80 to 100 percent of the time during the peak period. Less than 100-percent operation of the total system is generally used to allow for downtime caused by adverse climatic conditions, such as wind or rain. Flexibility in system operation will usually allow time for crop harvest, so no additional reduction in percentage operation would be required for harvest. Sizing can be obtained by taking the design peak application (20 percent for July on figure V-1) and dividing by the percentage operation (say 80 percent) to obtain the system capacity (25 percent of the annual volume during the peak month or three times the average annual flow rate).

Irrigation

The purpose of the irrigation system is to apply the effluent uniformly on the fields at the desired rate, allowing for rest periods between applications. The irrigation system is normally owned by the individual farmer. Irrigation systems may have a lot of hardware consisting of sprinkler systems which automatically irrigate entire fields or may have a minimum of equipment and high labor requirements for operation. The mechanized systems provide the best irrigation uniformity and the best system control and therefore are recommended for land application. Both sprinkler and surface irrigation may be appropriately used under the proper conditions. Selection of the irrigation method is discussed in Design Factors – I.

Surface Drainage

Surface drainage systems will collect natural surface runoff or runoff water from a surface irrigation system. The runoff may be returned to the storage system or discharged if the quality is suitable. Discharge requirements for coliform or fecal coliforms may make such a system necessary. If a surface drainage system is required by the state to collect natural runoff, it should be sized for storm runoff with recurrence intervals of 2 to 10 years unless the state has specific requirements. The runoff collection system should be emptied within a few days after the storm.

Subsurface Drainage

A subsurface drainage system may be required to prevent a water table from rising into the soil root zone. However, a groundwater table is necessary for a drainage system to work. The system may consist of wells, buried drain line, or open drainage ditches. Buried drain lines of concrete, tile, or plastic are usually most satisfactory. Inflow into the line occurs between joints in the concrete or tile and through slits or holes in the plastic. Only rarely will a drainage system recover all of the applied effluent. Usually flow will occur beneath the drain lines around the site perimeter. A subsurface drainage system is often required where applications are significantly above those required for irrigation.

A drainage system should be designed to drain the necessary quantity of applied effluent and precipitation. The water table should be drawn down within a few days after an effluent application or a major rainfall.

Spacing of the drainage system will be controlled by permeabilities and depth of wetted materials. Standard procedures are available for designing drainage systems under nearly all conditions. Where high loadings occur as in the infiltration-percolation process or where permeabilities are low, drain spacing may be as close as 50 to 100 feet. Where higher permeabilities occur and the loading is consistent as with the high-rate irrigation process, drains may be spaced much further apart, up to 500 feet or more. Careful consideration of the drainage for land application is a necessity, and normally some field investigation is required to specify spacings and depth even in preliminary studies. Much more detailed investigation is required before final design.

Buffer Area

A buffer area around the application site may be provided for aesthetic purposes or for protection from pathogen transmissions if the effluent has not been disinfected. Some states require buffer areas around the land application area. Other states have no requirement or leave it up to the engineer. No set design criteria can apply to all situations. In the absence of specific state requirements where biologically stabilized but nondisinfected wastewater is applied, a buffer width of 400 feet (200 feet with shrubs or trees) appears adequate for most sprinkler or spray systems. With adequate disinfection, the buffer may be reduced where there are no specific state requirements. With surface irrigation, tailwater runoff control is required, but no buffer zone is necessary.

The minimum travel distance of water droplets can be estimated from fall velocity, water droplet particle size, and distribution and wind velocity. Prior to establishing buffer distances, a detailed analysis of requirements should take into consideration wind velocity, wind direction, downwind development, and the irrigation system to be used. For some irrigation systems and sites it would be possible to incorporate operating options into the irrigation system design so the downwind portion of the system could be shut off during moderate wind conditions. If wind becomes high, it may be necessary to shut down the entire sprinkler or spray system. A buffer area as a fixed condition or as an operational condition can be effective in minimizing wind drift of water droplets from sprinkler irrigation systems. Surface irrigation should not produce a wind drift condition.

Monitoring System

The purpose of the monitoring system is to detect quality problems in the wastewater, soil, plants, percolate, and runoff and to provide a data base for future reference. The monitoring system should give previous warning of a potential problem such as accumulation of heavy metals approaching a limit, adverse changes in plant growth, or inadequate pollutant removal. The type of tests and locations of the sampling points are critical to obtaining meaningful results. Obtaining a statistical significance may require many samples. The design of the monitoring system should consider the variability of the parameter being measured.

Location of the sampling points can determine whether or not a problem would ever be detected. When a monitoring system is designed without proper consideration to water movement through soil or porous media, it may not be properly located to detect pollution. A detailed monitoring program should be developed for each system designed. The location of sampling points should give proper consideration to water flow lines[27,30] and travel distances. A hydrogeologic investigation may be required to determine the best monitoring locations.

Monitoring points for a hypothetical application site are shown in figure VI-1. If samples are taken at A and B, flow lines from the application area indicate no treated effluent would reach these points. It may require several years for treated effluent to reach point C because the flow lines are a long distance from the application surface. If samples were taken from point D, mixing with water from sources other than effluent could make results invalid. If samples are collected at point E in the groundwater and near point F in the soil, the samples should show a quick response and should be representative of the system operation.

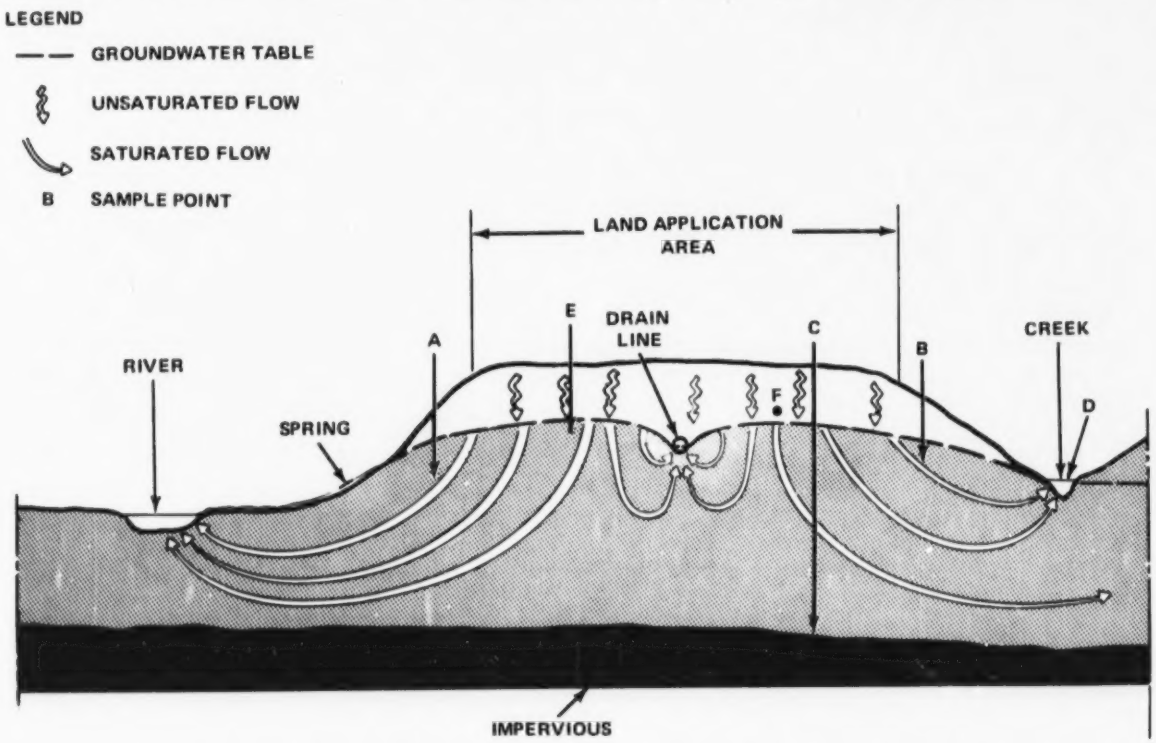

Figure VI-1. Typical land application site and possible monitoring points.

The frequency and number of samples and parameters measured must also be determined for each project. Because of the variability involved, it is more difficult to get representative samples of plant vegetation than of soil or water. The same point on the plant must be sampled at the same time each year in order to get an accurate indication of change. Some elements are concentrated in one place in a plant and not in others. Where to sample for what must be determined for the plant species involved. A great deal of help can be obtained from universities and various specialists about what to measure and where.[27,30,31]

OPERATION COMPONENTS

A land application system must be properly operated and managed or it may not meet the treatment objectives and could be a public health nuisance. As indicated throughout this report, many complex factors are involved in land application, making it very difficult to have total control over the treatment process. The soil and plant system is adaptable to considerable environmental stress and thus allows some variance in land application operations, but the crop or pollutant parameters may show the results of this stress.

Crop

One of the most important aspects of managing a land application project is the crop selection. For annual and perennial agricultural crops, it is easy to change the crop during the project life. Factors which influence the crop selection are the crop's nutrient removal efficiency; suitability to the climate, soil and water applications involved; and tolerance to wastewater pollutants. If the crop is to be harvested, the local market for the crop must be considered. In addition, the time and costs for planting, harvesting, and caring for the crop compared to the expected return are also important in the crop selection.

If removal of nitrogen is a primary objective, a perennial forage grass appears to be the best selection because it can remove nitrogen to low concentrations.[32] Reed canary grass has been shown to be effective in removing nitrogen; however, other grasses may be just as good and may respond better under some circumstances. Climate, soil properties, and market for the crop as well as nutrient removal will affect the crop selection.

The amount of nitrogen removed by selected crops was reported earlier in table IV-2. However, very little information is available on the removal efficiencies at low element concentrations. It may be possible to adapt data on fertilizer versus yield to get nitrogen removal efficiency as follows:

$$E_n = \frac{N_r}{N_a} \times 100,$$

where E_n = crop nitrogen removal efficiency, N_r = total nitrogen removed with the harvested portion of crop, and N_a = total nitrogen applied in wastewater. However, with fertilizer experiments the purposes are different, and the depth of applied water may influence the results dramatically.

Forests are much less efficient than crops in nitrogen removal. Forests, particularly deciduous trees, consume large amounts of nitrogen in annual leaf growth. This nitrogen is then recycled when the leaves drop. With low effluent applications of 1 inch/week, the nitrogen at the 4-foot depth was found to increase considerably over the nitrogen level with no application but was still below the nitrate-nitrogen limit of 10 mg/l for drinking water supplies.[32] When applications of 2 inches/week were made, the nitrate-nitrogen generally exceeded the concentration limit of 10 mg/l. Thus, to apply effluents to forests, the nitrogen limitation will have to be lower than that for agricultural crops.

Crops vary greatly in tolerance to pollutants, such as boron, salts, and specific ions. Consideration must be given to the wastewater quality in selection of the crop to be grown. Effluents applied to corn and reed canary grass have been shown to have beneficial effects[33] in the eastern United States. However, adverse plant responses to irrigating with wastewater have also been noted,[34] and the costs associated with quality changes when wastewater is used for irrigation have been documented.[35] Most of the adverse effects of using wastewater for irrigation can be overcome with proper design and management. There may be a difference in plant responses to wastewater between the eastern and western United States.

Because of the many different factors involved, the crop must be specifically selected for each project. The agronomist or plant physiologist familiar with the local area should be helpful in selecting a crop for a land application alternative. Consideration must be given to the many factors mentioned above. In addition, changing crops is an option in management of the wastewater treatment system. Such a change could greatly affect the nitrogen balance and resulting nitrogen removal.

System Management

System management includes management of the crops, soil, irrigation, and monitoring as well as mechanical equipment. A system evaluation and design cannot be complete without proper consideration of how the system will be operated as a unit. Considerable planning should go into development of a wastewater irrigation plan with enough flexibility to allow for adequate crop management including planting, tillage, and harvest. It has been stated that good crops indicate good wastewater treatment; thus, adequate planning for good crops must be done. Other system management factors include site ownership or lease, farm operation, and monitoring.

The following three alternatives are available for acquiring rights to use a specific site for wastewater treatment:[36]

- Obtaining the site in fee
- Obtaining a real property interest in the site other than fee (easement or lease)
- Contracting with the land owner or water user to take wastewater for irrigation (no interest in real property is acquired)

Because of expensive site development and a need for long-term reliability of the treatment process, the site is usually acquired in fee. This allows the greatest flexibility in land use, but public ownership may remove the land from real property tax roles.

The Corps of Engineers[36] indicates that acquiring and maintaining interests by leasing may in the long run equal or exceed the cost of acquiring the site in fee. However, the social and political impacts of less-than-fee property interest may override the potentially higher cost and reduced flexibility in land use.

Contractual agreements between the land owner and the agency with wastewater have been developed for irrigation of agricultural crops.[37] The application of the contractual agreement is discussed further in the paper prepared by Culp for this seminar.

Local practices for farm operations and leasing arrangements should be considered in establishing the management and operation structure. The options for management and operation are so diverse that they cannot adequately be covered in this discussion. The overriding fact is that in most cases (except the irrigation process) the objective is to treat the wastewater. The management and operation must provide treatment of the wastewater to the required level prior to discharging it to surface or groundwaters. If management of the treatment system conflicts with farm management, the farm management must be modified as necessary.

The land application system which is controlled by the implementing entity (i.e., it has property interest in the site) could be operated in the following ways:

- Managed and operated by the implementing agency
- Managed by the implementing agency and operated by a private party through contract or crop sharing
- Managed and operated by contractual agreement with the same private party
- Managed by contractual agreement with a private party and operated by a subcontractual agreement with another private party

Close cooperation between the treatment system management and the farm operation is required in all cases. Scheduling of irrigation with farm operations such as planting, tilling, spraying, and harvesting is vital to successful management. If adequate consideration is not given to the system operation, the design may be inappropriate. For instance, if crops are to be harvested, flexibility is needed in the irrigation system for sufficient drying and harvesting time. Farm management specialists can be helpful in setting up the management of the crops, soil, and irrigation portions of the operation. These specialists should be consulted during the planning stage.

Chapter VII

ALTERNATIVE EVALUATION

An evaluation for land application alternatives is based on economic, engineering, and environmental considerations. The importance of these factors, especially the environmental consideration, will vary with the local community, depending on its goals and objectives. The importance or weighting which is given to each factor will vary greatly between individuals, making an objective evaluation virtually impossible.

A recent paper by Davis[38] discussed the impacts of land application on the metropolitan environment. The areas discussed were:

- Shaping of metropolitan areas through massive land acquisition programs
- Regional organization structure necessary to execute a land application treatment system
- An accelerated development backlash to control crowding in the surburban and urban growth areas

Potential problems identified were land costs, difficulty of implementing regional projects, need for sales effort, potential legal action, reduction of tax base, and time and expense for human relocation. The land application option can be a new force in shaping urban sprawl because it potentially involves the largest domestic land acquisition program for metropolitan regions since the open space program.

Because land application alternatives can have major social ramifications, active public involvement in their evaluation is nearly a requirement when options involve large or diverse impacts. Consideration of potential impacts such as controlled land use and control of urban sprawl cannot be measured as an engineer measures costs. Thus, most engineers find themselves out of their field of expertise in projects involving major and diverse impacts.

Evaluation of alternative plans by the engineer alone is less common now than in times past. Instead, planners and environmentalists are becoming involved as team members in land application projects, and efforts are being directed at public information and involvement. Printed matter summarizing the project and major effects is often prepared for distribution to the public. Newspaper supplements are used a a means of "selling" the alternatives.

Thus, an engineer must depend more on input from many disciplines and may not make the final recommendation. Instead, the final decision will be made by the local decision makers (elected representatives). They may seek guidance and recommendations from citizens groups and special committees. The engineer is the technical consultant to the decision makers and to a limited extent to the advisory groups. Through team effort the engineer and planners can bring together summaries of major features of the alternatives. The advantages,

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disadvantages, and major features of each alternative may be listed or a matrix table may show the features and impacts for each alternative. The engineer's (project team's) challenge is to put the summarized considerations before the decision makers and advisory groups and possibly even the public in an unbiased manner. The decision makers must choose the alternative which best accomplishes the treatment objective within the goals of the local area.

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